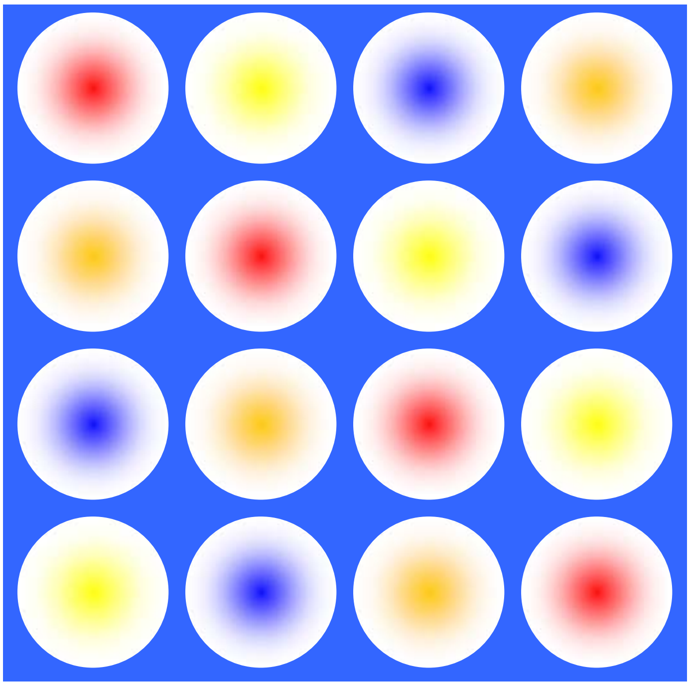
JRC Scientific and Technical Reports

Proceedings of the International Workshop on:

Status, Prospects and Strategies for LEDs in General Lighting

Ispra, Italy – 3 & 4 May 2007

Editors: Paolo Bertoldi and Bogdan Atanasiu



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EUROPEAN COMMISSION

Institute for Environment and Sustainability

The mission of the JRC-IES is to provide scientific-technical support to the European Union's policies for the protection and sustainable development of the European and global environment.

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Summary of the International Workshop on:
"Status, Prospects and Strategies for LEDs in General Lighting"
Ispra, Italy – 3 & 4 May 2007

There is a renewed and urgent call by policy makers at all levels (G8, EU, etc.) for a more efficient use of energy as a key element of the climate change mitigation policies. Lighting consumes in the European Union about 96 TWh per year in the residential sector (about 14% of total residential electricity consumption) and about 175 TWh per year (or 26% of total electricity consumption) in the tertiary sector, including street lighting.
At a global level the IEA has estimated that grid based electric lighting consumes 19 % of the total global electricity production or about 2600 TWh per year.

In particular in the residential sector lighting is still dominated by an old and inefficient technology, incandescent lamps, which have been around for the last 100 years. These lamps have a very low efficiency wasting more than 95 % of the input energy to produce visible light (with typical efficiency from 10 lm/W up to 22 lm/W for the best halogen lamps).

Several policy makers have started to announce the phasing out of this obsolete technology. Australia has announced the phasing out by 2012, this was followed by some north America States such as California. Recently at the last European Union Summit in March 2007, EU leaders also asked the Commission to investigate a possible phasing out of inefficient and wasteful incandescent lamps.

The 'traditional' energy efficiency solution for lighting in the residential sector has been the Compact Fluorescent Lamp (CFL). CFLs have improved over time in terms of size, performance, quality and at the same time their costs have reduced. However CFL's are not accepted by all users as an incandescent replacement for performance and aesthetic characteristics (size, shape, colour rendering, light directionality). Currently, CFLs are promoted through a number of policy mechanisms, however the functionality of CFLs ensure they cannot completely replace all incandescent lamp applications, for example within reflector lamps and spot halogen lamps.

Recently Light Emitting Diodes (LEDs) have become a serious alternative light source for generating white light. LEDs, discovered for the first time by H.J. Round in 1907, were re-discovered in 1962 by Nick Holonyak and S.F. Bevacqua from General Electric. Since then there has been an increasing investment and development in the LED performances and applications resulting in an increased market size. Initially LEDs had a very low efficacy of about 0,1 lm/W and were used mainly in portable devices (calculators, watches, etc.) and to indicate the operational mode of electronics products, providing coloured light (red, yellow, green). Only from the late 1990's have LEDs been used in lighting application, e.g. for LCD backlighting (mobile telephones), traffic lights, automotive applications, signs and signals (in this latest application mainly coloured LEDs). More recently LED manufacturers have claimed very high lumen efficacy exceeding 100 lumens per watt.

The European Commission Joint Research Centre is currently reviewing the most efficient technologies that impact upon the electricity end-use, together with their cost and environmental impact, in order to asses their possible impact on the European energy saving targets. The European Commission Joint Research Centre organised a workshop dedicated to the latest R&D, market information, and application on LED for general lighting, in order to gather the latest information to the topic. Beside LED researchers, market analysts, and LED manufacturers, several luminaire manufactures and lighting experts were invited to contribute their views on the possible use of LEDs for general lighting.

The first part of the workshop was focused on the LED market development.

Robert Steele of Strategies Unlimited presented an updated view of the LED emitter market. The LED emitter market continued to grow in 2006 with similar patterns to 2005 with market growth of 6% to $4.2 billion, the slower growth is due to a reduction in the rapid growth seen in recent years within the mobile phone market (mobile applications is 48% of the total high brightness LED emitter market, while illumination represents only 5 % of the market, but is the fastest growing segment). The majority of lighting applications are for colored (R,G,B) light, but white light is starting to emerge.

The 2006 market for high brightness LED emitters used for lighting was $205 million. This market is growing at around 37% per year – the highest of any HB LED application, and it is projected to reach about US$1 billion by 2011. Volume shipments of LED emitters are expected to significantly increase during this period however the average selling price of LED emitters will continue to drop resulting in the outlined revenue growth. The majority of applications use RGB LEDs today, but white will increase to more than 60% of the total market by 2011. The solid state lighting market drivers according to Steele are: the visual appeal; saturated colors, small apparent point source of light, design flexibility; long lifetime, robust, and ideal for applications currently requiring high maintenance costs; compact form factor; lack of radiated heat or UV (important for the retail sector and the new EU directive on optical radiation); low-voltage operation; increasing energy efficiency. Other advantages are colour variation and dimming.

Today the major application for LED lighting are: retail display lighting (very effective in cold temperature applications such as frozen food display cabinets); residential (still a niche market); street lighting; architectural (mainly for outdoor application, such as facades, gardens, monuments, but increasingly used in 'trendy' spaces, such as clubs and restaurants, and starting to be used within indoor white applications).

The other speakers during the first day all indicated clearly that the LED efficacy continues to improve and several LED emitters have achieved or are approaching 100 lm/W in production for cold white applications around 5500K (efficacy is usually measured at about 350 mA, which is about 1.2 W input power). All the speakers highlighted that high-power LEDs (e.g. at 1000 mA) are less efficient, and that warm white LED have a lower efficacy (between 20-30% lower than the cool white LED equivalents). Speakers also highlighted that there is a difference between claimed manufacturers data sheet performance values and real life applications values (Poorer performance is seen at much higher LED emitter junction temperatures and in steady state conditions). It was highlighted that the test methods to measure LED performance and safety are currently under developments. Power LEDs are improving rapidly and continued improvement is expected. Performances of 100 lm/W are already available and about 150 lm/W is likely in the near future (for the time being this has been reached only in the research labs, and for low power LED dies). The theoretical efficacy of white LEDs is considered to be beyond 200 lm/W. As efficacy increases, thermal management, one of the major problems with LED fixture designs, is simplified and system costs can be reduced. Key areas for future improvement are white colour uniformity, choice of CCT and high CRI.

Although the LED efficacy is important the optical (fixture) and electrical (driver) efficacy are equally as important but often misunderstood or ignored.

Among the various example of LEDs light sources on the market for the residential sector the following is illustrative of the best available technology today: Warm-white 2700 or 3500 K, 650 lm at 11 W wall-plug power (this is equivalent to a 60 W GLS lamp) 60 lm/W efficacy (wall-plug), with a colour rendering index 92.

Besides the high efficacy of white LED emitters the efficiency for both AC/DC and LED driver stages has exceeded 88% for high power lighting units (>15W). For LED drivers, closed-loop feedback designs are now available to ensure the performance of the LED based lights is stable over time. Such control technology will enable LED lights to transform from a basic “dumb” light source to a smart full function light processor.

In addition to the LED efficiency, in comparison to other light sources many speakers indicated that the usable light is much more important, LEDs may have very efficient drivers (80 to 90% efficiency) and also very efficient optics (again in the range of 80%), while CFLs have a poor lighting distribution and the final efficacy can be as low as 20 lm/W. For example an LED with 80lm output at typically 1,15 W (3,3V x 0,35A) power consumption with a “nominal” (Tj = 80°C) operating condition and a driver efficiency of 85% results in: 80lm x 0,85 / 1,15W = 59lm/W; with an optical efficiency of 80% we arrive to a final efficiency of 42 Lm/W. With a CFL starting from the lamps efficacy of 50 lm/W, a final efficiency of only 23 lm/W is achieved.

Other key areas of current research are developments in phosphors, a key material for solid state lighting used to create different white light spectrums from blue light LEDs, while preserving the optical efficiency.. Further presentations described the investigation to improve the output performance attainable by etching Photonic Crystals and Photonic Quasicrystals (PQC) into the top emitting surface of LEDs (PQC-LEDs).

The presentation by Wolfgang Budde addressed the current and future OLED technologies and trends. The speaker presented a short state-of-the art overview of white OLED developments, highlighting 'the world records' including white OLEDS achieving around 32-64 lm/W at 1000cd/m2. The second part of Mr. Budde presentation was an analysis of the power LEDs and of the efficiency improvement challenges of the power chain from 'electricity-in to the light-out'. The overall performance of the power chain is influenced by many parameters and optimisation is necessary for: colour shift over temperature, efficacy decay over driving current, resulting colour shift over drive current for composite light sources. The electronic drivers are also highlighted as the subject of future improvements including variation of the electrical structure of the power LEDs within a fixture and paying attention to the stand-by consumption of the lighting equipment.
In conclusion, LEDs and OLEDs are already efficient but the overall system optimisation is very important and requires a high level of control and automation which still remains a challenge. In order for the drive electronics to match the potential lifetime of an LED light source it is important to completely understand the luminaire design and requires a close working relationship between the light source manufacturer and electronics supplier.

The second day of the workshop was dedicated to presentation by lighting experts, luminare manufacturers, lighting designers and industrial designers.

It was highlighted by speakers that LEDs are still a niche application in lighting, though LEDs could offer many advantages. The initial costs per 1000 lumens of white LED light are currently 2 – 50 times higher than conventional light sources (including the more expensive light sources such as the T5 fluorescent). The lumen cost of LEDs has dropped by about 30% during the last year.
However long lifetime, energy savings, low maintenance costs can help to compensate the high initial costs of LED’s over lifetime, and thus the Total Cost of Ownership (TCO) may be comparable to or better than those offered by other conventional light sources.. Another niche application is using LEDs together with Photovoltaic cells (PV). This niche application, mainly for garden lighting in developed country, can immediately offer a cost-effective solution for lighting in off-grid situations in developing countries. An important factor is that LEDs can improve dramatically the quality of lighting and also improve the indoor air quality compared to fuel based lighting whilst significantly reducing the cost of lighting.

While the residential sector lighting is still a new lighting application for LEDS they have been sold mainly as a fashionable and expensive light source. LEDs are already making a break through in the retail sector (fashion and jewellery shops), and frozen food cabinets in supermarkets. Mr Frazer, a light designers showed the very attractive and innovative design that can be created around LEDs. In his views LEDs offer professional designers a lot of opportunity for creative design. Similar views were also expressed by other lighting designers where LEDs were said to offer unique opportunities for architectural lighting and the use of vivid coloured light.

Luminare manufacturers also expressed great interest and attention for LEDs. Among the design advantages offered by LEDs the following were mentioned:

- Small design;
- Small dimension (Very compact dimensions of lighting fixtures);
- Can fit in conventional light fittings;
- Dimming is possible without change in colour temperature;
- Colour of light is adjustable (with use of multi-coloured LEDS). Dynamic colour control (RGB multi-chip LEDs, individually controlled) and high colour saturation
- Large range of colour temperatures
- Long operating life
- Resistance
- No maintenance costs
- Higher luminous efficiency
- Clean light without IR and UV
- Safety, because of very low voltage
- Very reduced amount of heat (no risks of burns)
- Cold switch-on (– 40°C), solid configuration non sensitive to cold temperatures
- Direct exact luminous emission without accessories or refractors
- Use of efficient optics made of polymers

Current evidence gathered at the workshop highlighted that the very latest LED emitter technologies had not yet translated into commercially available products therefore current consumer-based LED products utilising older technology are not yet able to replace compact fluorescence lighting in terms of efficiency and price. However, LED products are now beginning to replace small wattage Halogen lighting units within retail, kitchen and bathroom applications.

It is clear that LED fixture designs have to be carefully designed and planned before installations.

It was also highlighted that:

- Realistic operational performance has to be declared by LED manufacturers;
- There is a lack of standards to measure and declare LED performances;
- Poor education of users for the acceptance and right use of LED;
- Poor CRI;
- different control and standards interfacing;
- Lack of colour consistency and binning (although this is being addressed);
- Different approach to design (e.g. mechanical/electronic design fully integrated).
- Outsourcing design of strategic components (need particular attention due to the increased weight of electronics value) or companies need to acquire in-house new specific expertise

In addition, LEDs are not to be considered as a standard lighting source: a conventional lighting fixture is designed to host a standard light source (interchangeable); while a LED luminaire is built "around" an LED. Luminaire manufacturers should use their expertise for creating more efficient and attractive LED final products, this includes designing: the thermal management; the electrical optimization (driver); the optical optimization (secondary optics); optimized "fixture" design around the small LED size; and the control versatility.

Luminaire manufacturers and lighting designers expressed great interest for LED lighting, and indicated that LEDs offer several advantages not only for the energy efficiency performance. However there are still some major issue to be improved such as the need for realistic performance to be declared by LED manufacturers; the lack of standards to measure LED performances; poor education of users for the acceptance and right use of LED; poor CRI; different control and standards interfacing; and lack of consistency (binning).

There was general agreement that LEDs will become an important technology to reduce lighting consumption in buildings and other applications, by offering better light quality than fluorescent lamps, and reaching the same level of efficacy (or even going beyond it). OLEDs are still in the R&D phase but should bring additional savings, and further enlarge the solid state lighting applications.

[All the workshop presentations are available at:
http://re.jrc.ec.europa.eu/energyefficiency/html/Workshop_LED_34052007.htm]

Session 1

Chair: Keven Verdun, The Lighting Association, UK

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RENEWABLE ENERGIES

Results, Activities, and Outlook

Scientific Workshop
Status, Prospects and Strategies for LEDs in General Lighting
Hotel Europa, Ispra, 3-4 May 2007

Heinz Ossenbrink
Head of Unit
Renewable Energies
European Commission, DG Joint Research Centre

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Renewable Energies Unit:

Policy driven:

Council Decision 9/03/2007:

Mandatory Targets for Memberstates by 2020:

- 20% Renewables
- 20% less Consumption
- 10% Biofuels

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Possible Contribution of Renewable Sources to European Electricity Supply 2020

TWh	2006	2020	Increase	Share 2020
Wind	95	856	**17%/yr**	35.2%
Biomass	55	209	**10%/yr**	8.6%
Solar	2.5	150	**34%/yr**	6.2%
Total	**152.5**	**1215**	**15%/yr**	**50%**
Consumption	3040	2432	**-1.6%/yr**	*-44TWh/yr*
newRES-E	**4%**	**50%**		

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Activities of the Renewable Energies Unit

- Electricity End-Use Efficiency
- Renewable Energy
  - *Progress of Renewables*
  - *Biofuels*
    - *Well-to-Tank Study*
    - *Environmental Impact*
  - *Photovoltaic Solar Energy*
    - *Research*
    - *Resources and Costs*
    - *Performance*
    - *Lifetime*

RefSys:
Reference System for Renewables and Energy Efficiency

BioF:
Quality & Performance of Bio-Fuels

Solarec:
Solar Electricity

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Efficiency of Energy Technologies

Use	Techno-logies Today		Lost	Dated	Europ. Cons.	Technologies Today and Tomorrow	Cross fertilisation
Illumi-nation	Incandes-cent Lamp		96%	~1879	65 TWh	CFL and LED	Optoelectronics
Stand-By Loads	Iron Trans-former + Rectifier		80%	~1882	50 TWh	HF Switchers	Semiconductors
Car Drive Train	Com-bustion Engine		75%	~1862	280 Mtoe	Brushless DC Motors LiPolymers H2 Fuel Cells	Advanced Materials, Polymer Electrochemistry Electronics
Electricity Gene-ration	Steam Turbine		60%	~1885	218 Mtoe	Wind Photovoltaics	Aerodynamics Quantum Physics Semiconductors Thin Film Displays

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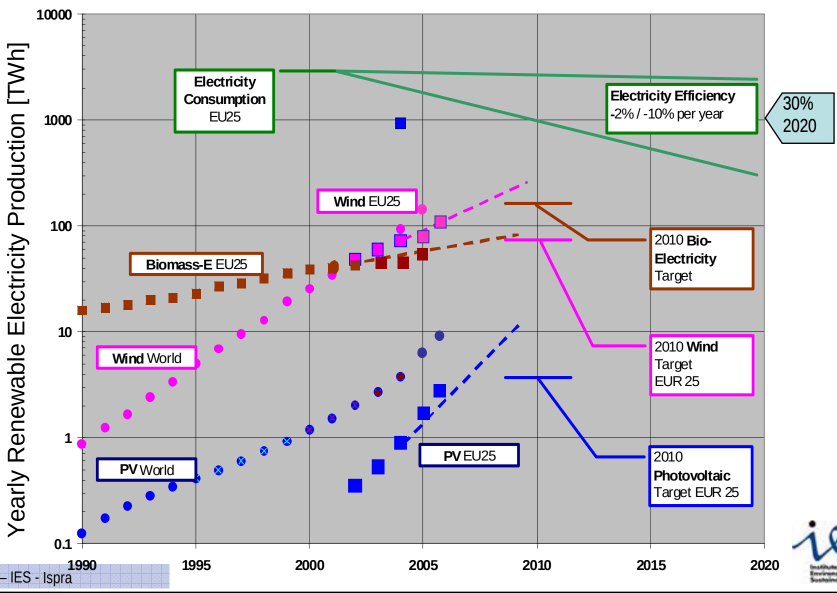
Progress of Renewable Electricity in EU25



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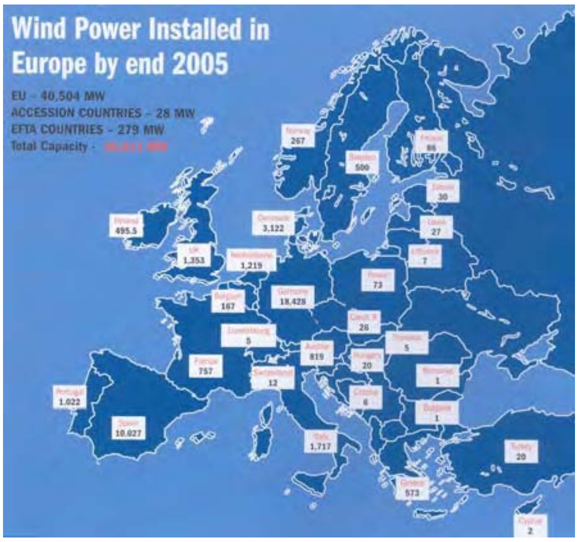
Progress of Wind Power: 3.3% of Electricity



	2006 added	2006 total
DE	+2233	20622
ES	+1587	11615
UK	+634	1963
PT	+695	1716
NL	+356	1560
FR	+810	1567
AT	+146	965
EU27	**7611 (+23%)**	**48062**

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Technology options, Biofuels

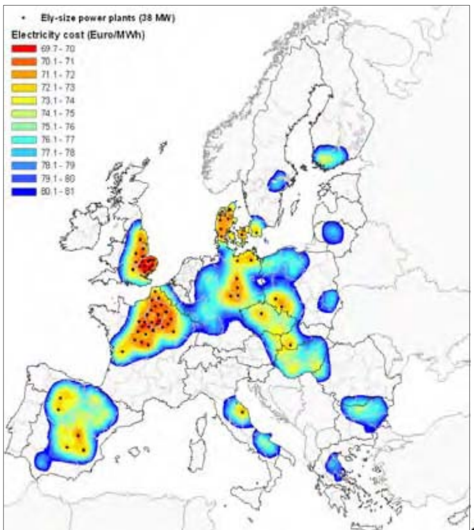
Ely power station   Economics/Optimisation   Suitability maps   Localisation

Effect of resource density on electricity cost

Steps:

straw density -> collection radius -> transport distance -> straw cost -> **electricity cost** (capacity is fixed)

Our theoretical sites have **electricity price 6.9-7.3 €cents/MWh**



Assumptions:
- *yearly consumption 200 000 ton + 50% reserve*
- *transport distance up to 50km*

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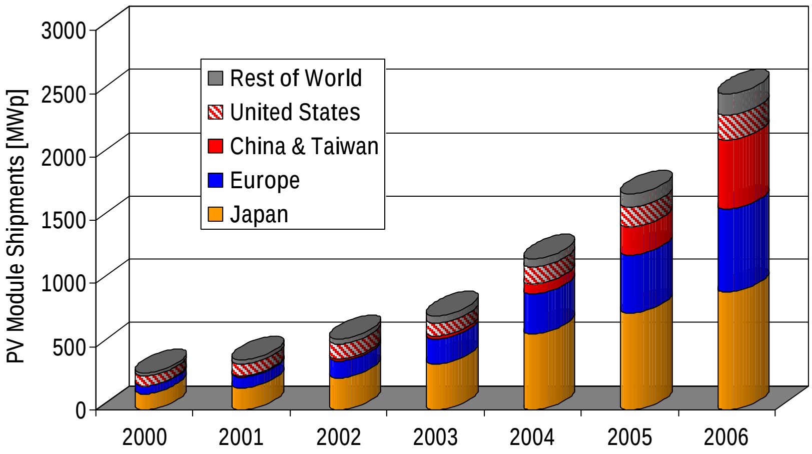
Photovoltaic: Steady Growth, 43% / year



Note: 1000 MWp produces 1.2 TWh of electricity per year

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European Solar Test Installation (ESTI)

- :Lifetime aspects of **2nd generation** PV-modules
  - encapsulants,
  - life-time electricity production
  - recycling aspects
- Exploratory research into **3rd generation**
  - **ultra low-cost** solar cells using polymer semiconductors
  - **ultra-high efficiency** (35% → 70%) solar cells together with 30 European partners
- Internet-based calculation of **Solar resources** in Europe
  - precision assessment of the solar availability on a 1km resolution (includes shadows and cloud formation)
  - cost-calculation of PV electricity on a regional level

ISO/IEC 17025
ACCREDITED

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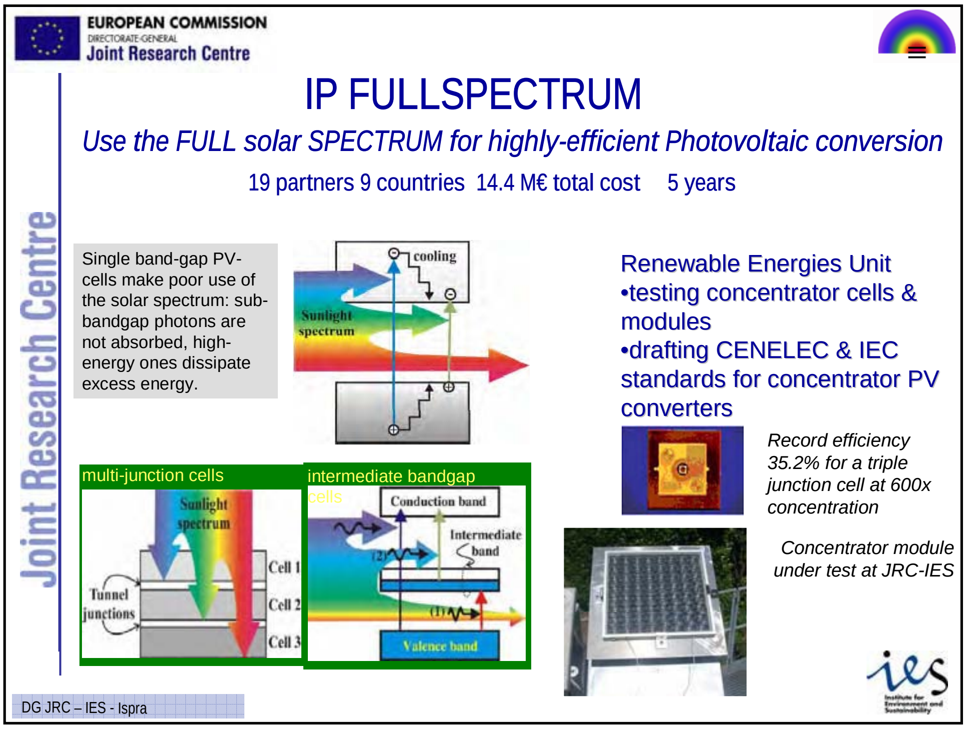
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IP FULLSPECTRUM
Use the FULL solar SPECTRUM for highly-efficient Photovoltaic conversion
19 partners 9 countries 14.4 M€ total cost 5 years
Single band-gap PV-cells make poor use of the solar spectrum: sub-bandgap photons are not absorbed, high-energy ones dissipate excess energy.
cooling
Sunlight spectrum
Renewable Energies Unit
•testing concentrator cells & modules
•drafting CENELEC & IEC standards for concentrator PV converters
multi-junction cells
Sunlight spectrum
Tunnel junctions
Cell 1
Cell 2
Cell 3
intermediate bandgap cells
Conduction band
Intermediate band
Valence band
Record efficiency 35.2% for a triple junction cell at 600x concentration
Concentrator module under test at JRC-IES
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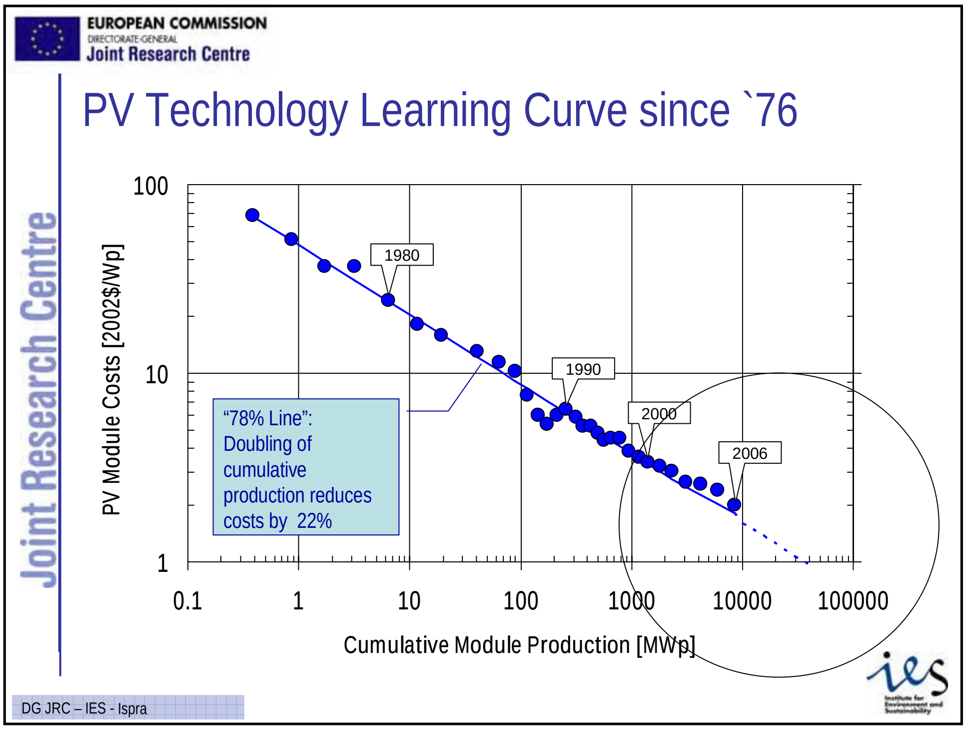
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PV Technology Learning Curve since `76
PV Module Costs [2002$/Wp]
100
10
1
1980
1990
2000
2006
"78% Line": Doubling of cumulative production reduces costs by 22%
0.1
1
10
100
1000
10000
100000
Cumulative Module Production [MWp]
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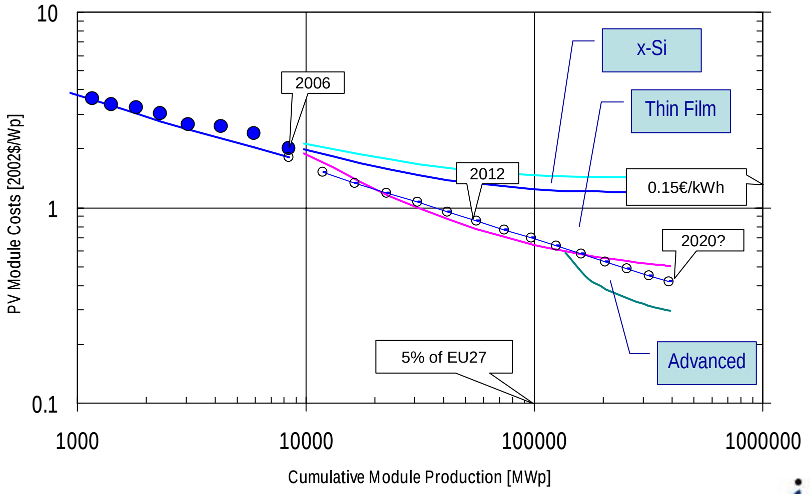
Learning Curve 2: The Interesting Part



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Anticipating future PV Research

New „Avenues”
- Cross-Fertilization with Industrial Production Technologies
  - Displays, Offset Printing, DVD, LED production.etc.
- Bio-Nanotechnology

Systems
- Low-Cost
  - Buildings, Tracking Systems
- Grid-Dispatch

Storage “Beyond H2”
- e.g. LiPo, integrated in Modules
- or even in Solar Cells?

M13 phage bound to nanocrystals

Assembly of Viruses on Multilayered Polymer Surfaces, Nature Materials, 5,234;2006

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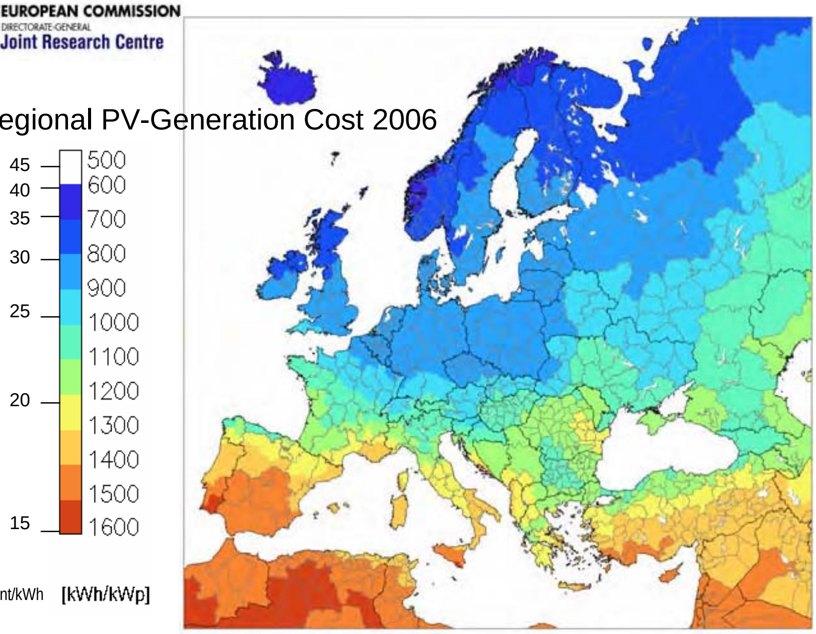
Regional PV-Generation Cost 2006



1 MW System Cost: 4 €/kWp, Interest: 3%, optimum tilt angle, 25 yrs lifetime, 0.5%/year O&M, PR 0.75

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Our Interest in LED

- Can we live soon without the incandescent lamp?
- Have LEDs a better environmental life-cycle than CFLs?
- We are convinced that new technologies are needed in the market, to achieve a sustainable energy supply
- Semiconductor and optoelectronics, a field of PV expertise
- Excellent opportunities for PV systems in developing countries

- *A 10 W PV module for 50€ can power 6W of LED's every day 6 hours, almost forever*

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15 years White LEDs:

Shuji Nakamura:

- In 1992 he pursued a route no one else thought would work (GaN). Like Edison, probably he has changed the world.

“While it took just one person to change the light bulb, there is no shortage of people who came close to stopping him doing it”

- It is good to see that he was recently awarded the 2nd Millenium Technology Price
  - » (1st: to Tim Berners-Lee, inventor of the WWW)

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Lighting Consumption and Saving Potential in the Enlarged EU

Paolo Bertoldi and Bogdan Atanasiu
European Commission DG JRC

Ispra, 3-4 May 2007

EC DG-JRC Workshop on "Status, Prospects and Strategies for LEDs in General Lighting"

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Energy Consumption of Residential lighting

- Lighting in the residential sector has been reported to consume 86 TWh per year in the EU-15 in year 1995 in the DELight Study (Environmental Change Unit, Oxford University). The DELight study predicted an increase of residential lighting consumption to 97 TWh by 2010.
- More recently the European Climate Change Programme (EECP) and the 2004 JRC Status Report calculated the following lighting consumption in the EU-15: 85 TWh growing to 94 TWh by 2010, without additional and new policies and programme introduced.
- Waide (IEA) calculated 79 TWh in 2005 for the OECD Europe.
- We calculated for year 2004, 79 TWh for the EU-15 and 96 TWh for the EU-27

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	no. of hslhlds [milions]	residential electricity cons. [TWh]	Lighting cons. [TWh]	Lighting cons. as share of total residential electricity cons. [%]	Average cons. lighting/HH [kWh]	Number of HH with CFLs [%]	CFL's/HH (including HH without CFLs)	Lighting points/HH
CZ	3,83	14,53	1,74	12	455,37	70	2,9	14
CY	0,32	1,32	0,24	18	749	79	2	16
EE	0,60	1,62	0,45	28	753,81	20	0,25	15
HU	3,75	11,10	2,775	25	740,48	60	1	18
LV	0,97	1,47	0,41	28	424,16	19	0,42	17
LT	1,29	2,07	0,62	30	479,72	20	0,25	10
MT	0,13	0,62	0,0806	13	630	50	1	15
PL	11,95	22,80	6,38	28	534,4	50	0,5	20
SK	1,90	4,90	0,4	8,20	240,05	50	1	15
SI	0,68	3,01	0,33	11	480	70	2	19
BG	2,9	9,31	0,9	10	310	34	0,5	13
RO	8,13	8,04	2,911	35,18	356,75	40	0,2	10
HR	1,42	6,07	1,1	18,11	773,76	39	1	14

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	no. of hslhlds [milions]	residential electricity cons. [TWh]	Lighting cons. [TWh]	Lighting cons. as share of total residential electricity cons. [%]	Average cons. lighting/HH [kWh]	Number of HH with CFLS [%]	CFL's/HH (including HH without CFLs)	Lighting points/HH
AT	3,08	15	1,1	7,3	357,14	70	4	26
BE	3,90	18,20	2,23	12,23	343,22	70,50	2,50	26,00
DK	2,31	9,71	1,36	14,00	589,00	65,00	4,90	25,40
FIN	2,30	12,20	1,7	13,93	739	50	1	23,5
FR	22,20	141,06	9,07	6,43	409	52	2,26	18,9
GR	3,99	16,87	3,04	18	761	50	1	12
DE	39,10	140,00	13,2	9,43	337,6	70	6,5	32
EI	1,44	7,33	1,32	18	920	38	1,5	18
IT	22,50	66,67	8	12	370	60	0,8	18
LU	0,20	0,75	0,098	13	487,5	70	2	20
NL	6,73	23,75	3,8	16	524	60	4	40
PT	4,20	11,40	1,7	14,91	404,8	54	1,7	11,4
ES	17,20	61,11	11	18	639,5	15	2	25
SE	3,90	43,50	3,4	16	872	55	3,3	32
UK	22,80	111,88	17,9	16	785	50	2	20

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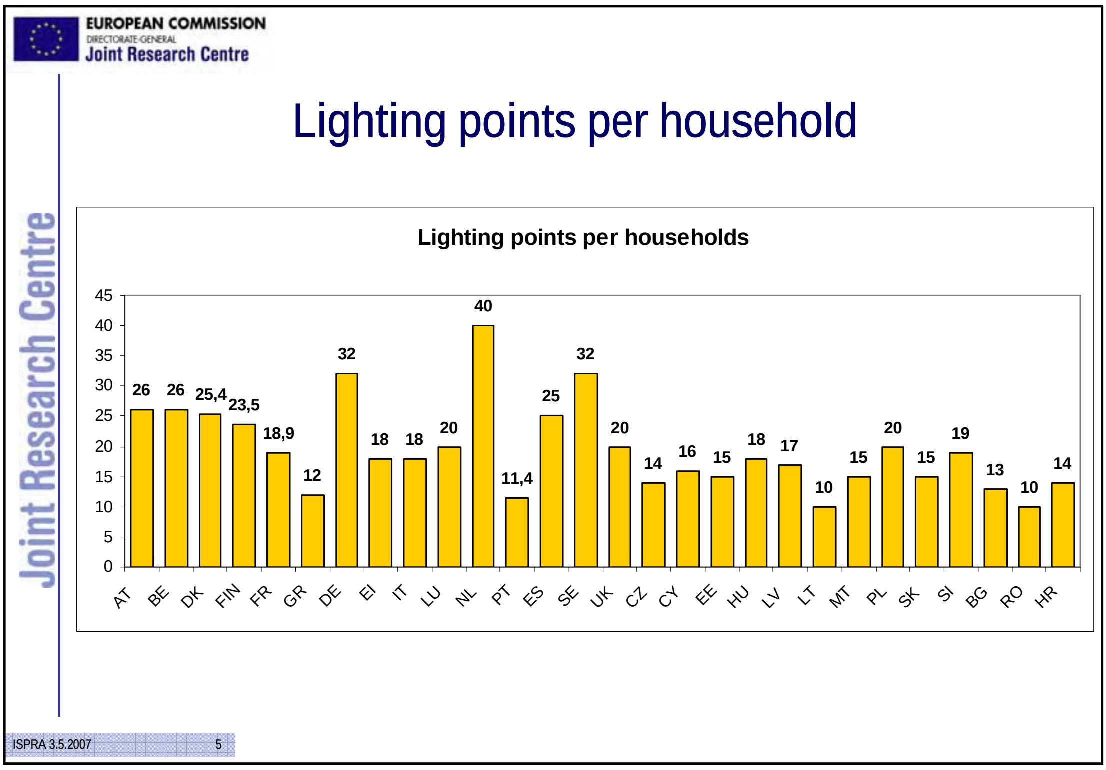
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Lighting points per household
Lighting points per households
0 5 10 15 20 25 30 35 40 45
26 26 25,4 23,5 18,9 12 32 18 18 20 40 11,4 25 32 20 14 16 15 18 17 10 15 20 15 19 13 10 14
AT BE DK FIN FR GR DE EI IT LU NL PT ES SE UK CZ CY EE HU LV LT MT PL SK SI BG RO HR
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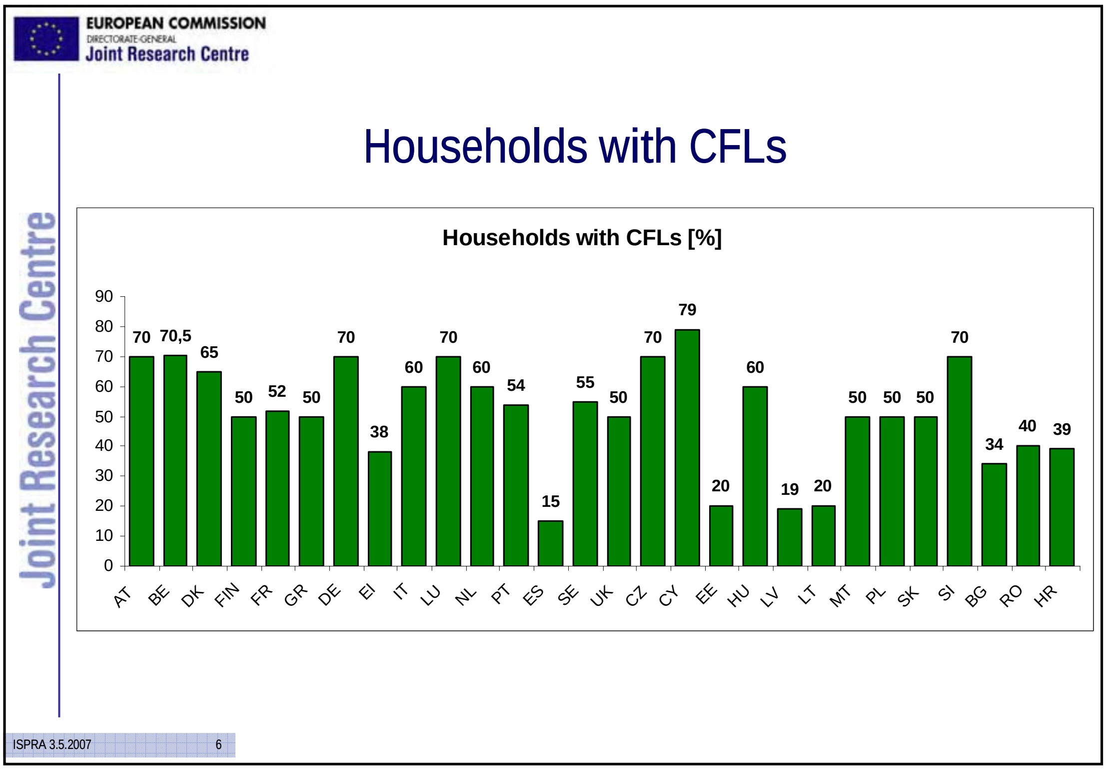
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Households with CFLs
Households with CFLs [%]
0 10 20 30 40 50 60 70 80 90
70 70,5 65 50 52 50 70 38 60 70 60 54 15 55 50 70 79 20 60 19 20 50 50 50 70 34 40 39
AT BE DK FIN FR GR DE EI IT LU NL PT ES SE UK CZ CY EE HU LV LT MT PL SK SI BG RO HR
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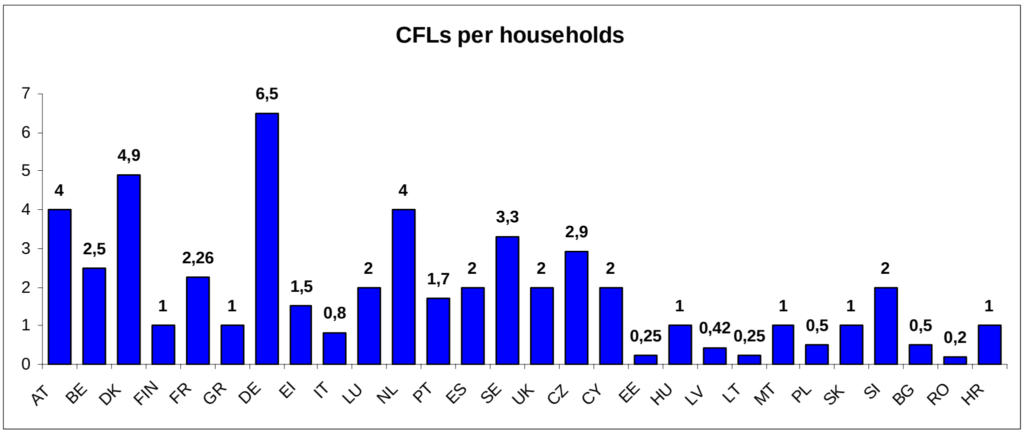
CFLs per household



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Increased sales of CFLs

Western Europe						
Product	Market (million units)					
	2000	2001	2002	2003	2004	2005
CFL-I	101	109	119	131	145	146
CFL-NI	72	78	80	82	87	92
Central & Eastern Europe						
Product	Market (million units)					
	2000	2001	2002	2003	2004	2005
CFL-I	14	21	27	34	41	
CFL-NI	9	10	12	13	15	

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	No. of hslhlds [milions]	residential electricity cons. [TWh]	Lighting cons. [TWh]	Lighting cons. as share of total residential electricity cons. [%]	Average cons lighting/HH [kWh]	No. of HH with CFLs [%]	CFL's/HH [including HH without CFLs]
EU-15	155,85	679,43	78,91	11,61	506,33	54,59	3,15
NMS10	25,41	63,42	13,42	21,16	528,20	51,97	1,01
EU-25	181,26	742,85	92,33	12,43	509,40	54,23	2,85
EU AC	11,03	17,35	3,81	21,97	345,54	38,42	0,28
EU-27	192,29	760,20	96,14	12,65	500,00	53,32	2,71

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Summary of the Findings

- Member States the lighting consumption as share of the total residential electricity consumption ranges between 8% and 23% (excluding residential electricity consumption due water and space heating are).
- The average consumption per household, which ranges from 337 kWh (Germany) to 920 kWh (Ireland) pa. [in DELight average household lighting electricity use ranges from 240 kWh pa to 920 kWh] . This consumption reflects the size (square meters) of the household, the burning hours, and the penetration of efficient lamps (explaining the very low consumption in Germany and high consumption in Ireland). The data for Greece is still under investigation, as the specific household lighting consumption is very high (but similar to the one of Cyprus and Malta). The lowest in New MS is in Slovakia, 240 kWh.
- The average number of CFLs per household ranges in EU-15 from 1 in Finland and Greece to 6,5 in Germany, where several promotion campaigns took place [in DELight the highest was NL with 2,7 followed by Germany with 2,1]
- In the new Member States the number of CFLs per household is substantially lower than in the EU-15 Member States, with the exception of the Czech Republic.

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Barriers to the penetration of efficient lighting

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- **Purchase price** is still an important factor (the most important one), even with the much lower cost of CFLs today. This is mainly explained by the fact that customer still do not have clear information about the short payback periods.
- **CFL quality.** In many countries consumers, who tried earlier version of CFLs, experienced in many cases CFL failures before the claimed life time, thus creating mistrust on this technology.
- **Aesthetic barriers**: shape, size and colour temperature of CFLs. Many of these barriers were created by older and bulkier CFLs, very often producing a very cold light, and having a slow light output stabilisation time Many of these aesthetic barriers have been removed (now CFLs come in different light temperature, in much smaller size and get to full output light in a very short time),
- The recent increase in the use of **halogen lamps**, in the shape of low voltage lamps, reflector lamps, and double ended high wattage lamps (for torchieres), limit the possible substitution of these type of incandescent lamps with CFLs, unless luminaires are replaced.
- In one recent survey in the German market customer were asked if they would purchase a CFL in the future. The same survey confirmed that the major barrier for CFLs is still the **'high' purchase price** when compared to incandescent lamps, even though 96 % of interviewed people **know that CFL save energy**, 86 % know that CFLs last much longer than incandescent lamps and even though 69 % know that the CFL have short pay back period.

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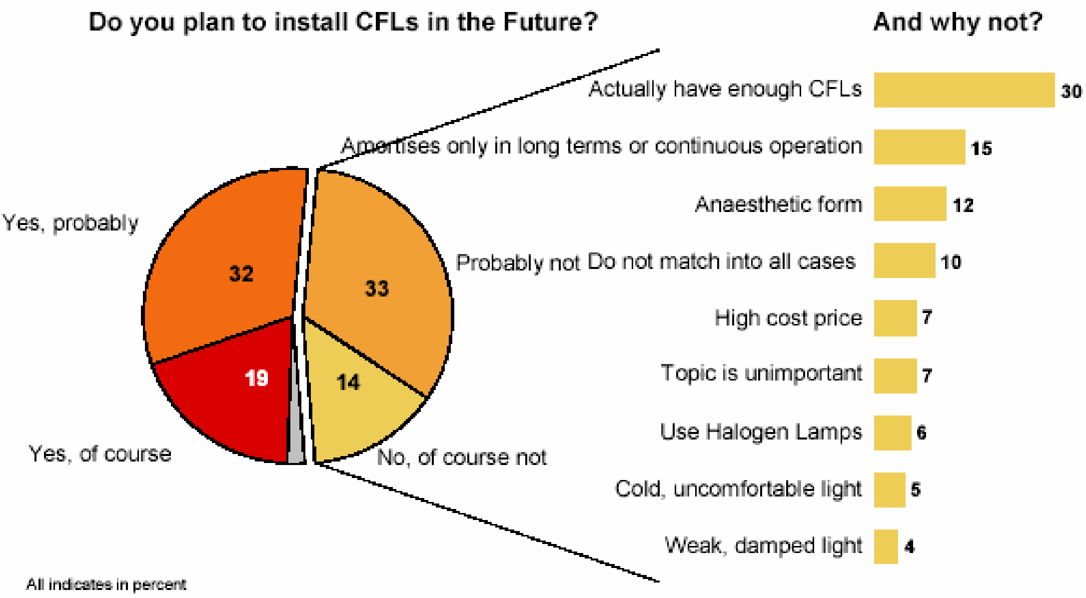

All indicates in percent

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Existing policies: Labelling and Eco Labelling

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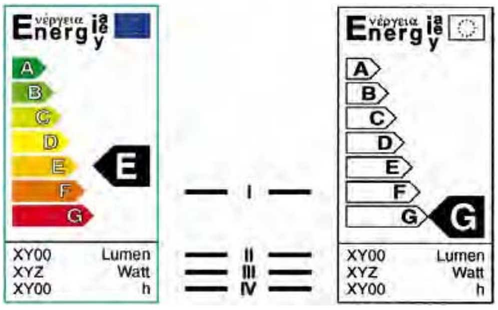

Directive (98/11/EC) adopted in 1998 and into force in 1999

	Single-ended with integral ballast (compact fluorescent lamps)
Energy efficiency	Class A
Lifetime	over 10 000 hours
Lumen maintenance	over 70 % at 10 000 hours
Average mercury content	maximum of 4,0 mg

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How much energy can we save with more soft policies?

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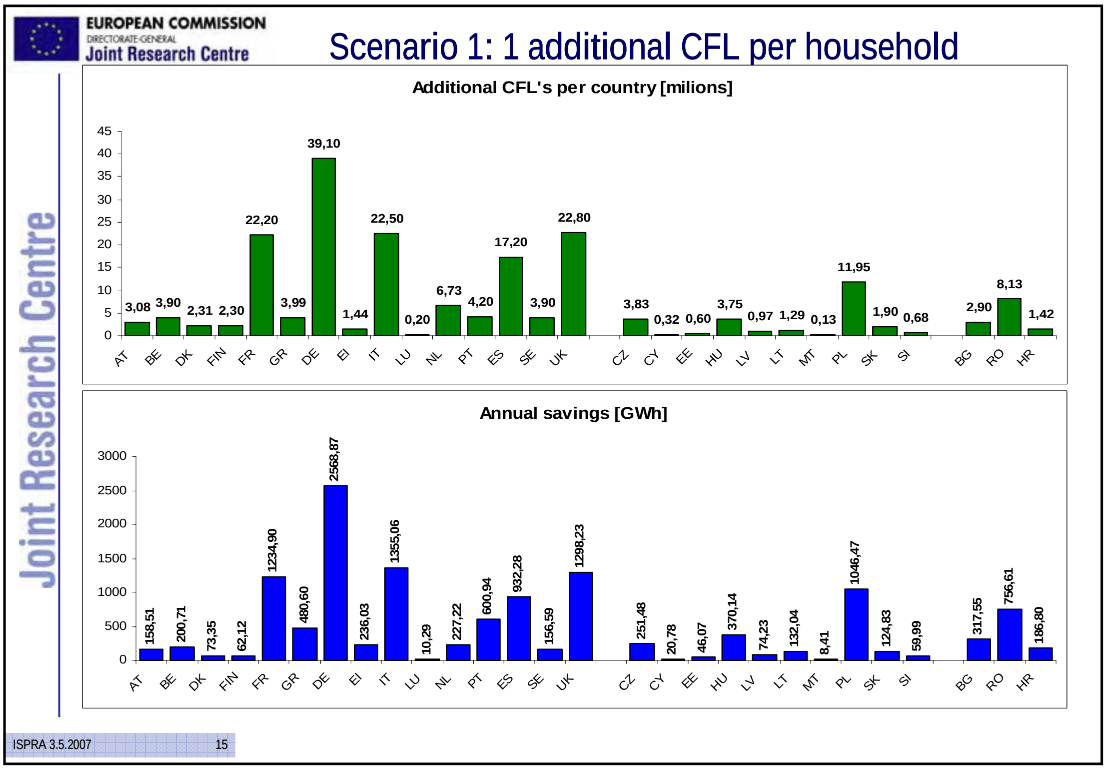
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Scenario 1: 1 additional CFL per household
Additional CFL's per country [milions]
Annual savings [GWh]
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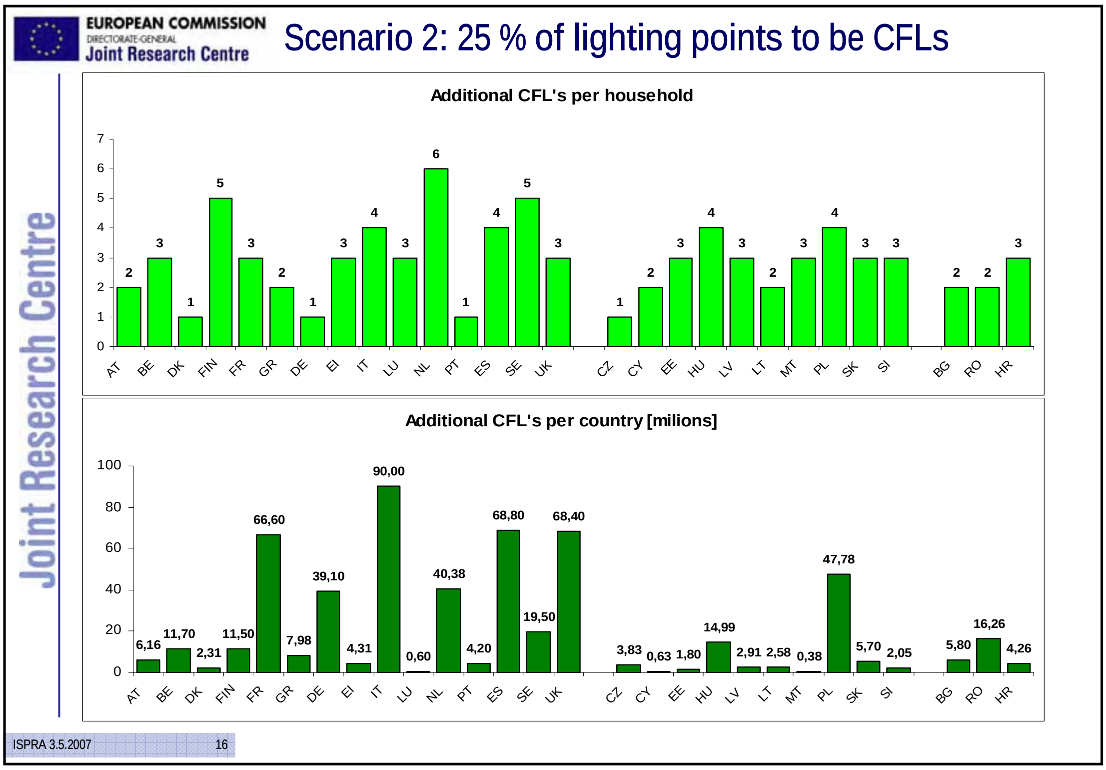
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Scenario 2: 25 % of lighting points to be CFLs
Additional CFL's per household
Additional CFL's per country [milions]
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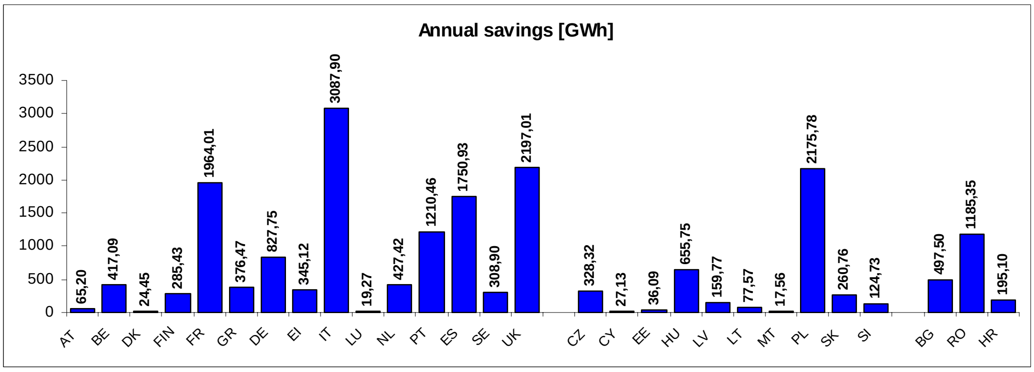
Scenario 2: 25 % of lighting points to be CFLs



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	scenario 1		scenario 2	
	no. of additional CFL's [milions]	savings [GWh]	no. of additional CFL's [milions]	savings [GWh]
EU-15	155,85	9595,71	441,54	13307,41
NMS10	25,41	2134,44	82,67	3863,47
EU-25	181,26	11730,15	524,21	17170,88
EU AC	11,03	1074,16	22,06	1682,85
EU-27	192,29	**12804,30**	546,26	**18853,72**

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Energy Consumption of non-Residential lighting (1)

Joint Research Centre

- Lighting is by far the major end-use category in tertiary sector consumption, responsible for about 175 TWh or 26% of total electricity consumption in the tertiary sector in the EU-27.
- As far as non-residential buildings lighting is concerned, this is dominated in lumen and energy terms by linear fluorescent lamps. T12 fluorescent lamps are the oldest technology of fluorescent lamps. These lamps have an efficiency of less than 75 lumens per Watt (lm/W).
- In the majority of cases there exists a T8 lamp that can be retrofitted into the same lighting point. Depending on whether this T8 lamp is a halo phosphor or a tri-phosphor the lamp efficiency can be improved to between 80lm/W (halo phosphate) and 90lm/W (tri phosphor).

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Energy Consumption of non-Residential lighting (2)

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- The T8 lamp now dominates the linear fluorescent market. The existing mix of lamps is still two-thirds halo phosphate lamps with the remaining third being three-band rare earth phosphor lamps which are currently increasing their market share year by year. Barrier coat technology has allowed the mercury content in current tri-phosphor lamps to be reduced to below 5mg
- The average lamp wattage for T12 lamps is 65 W (1500 mm long). The average energy saving per lamp when switching from T12 (65W) to T8 (58W is 12%). The total annual sales figure for T12 lamps in the European Union is 16 million lamps. This is more or less a stable replacement market. The total sale of linear fluorescents is estimated to be 350 million lamps per year. There is a relatively new technology, T5 which has a higher efficiency (95 to 105 lm/W) and is designed to be fed only by electronic ballasts (in addition these lamps perform best at a temperature of about 35 C, which is often the case in luminaires, while T8 perform best at 25C). However, the market penetration of T5 lamps is still limited, though slightly increasing overtime.

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Energy Consumption of non-Residential lighting (3)

Joint Research Centre

- Ballasts are needed to run every fluorescent or discharge lamps. There are two very different technologies for ballasts: the magnetic type and the electronic type. The latter lowers power losses and also allows operating the lamp at lower wattage for the same light output. There is a voluntary classification scheme for the combination of lamp ballasts introduced in the year 1998 by the lighting equipment manufacturers' trade association, CELMA. The classifications scheme18 together with the minimum efficiency requirements for ballasts (Directive 2000/55/EC), which came into effect in 2002, have resulted in a gradual market transformation. The Directive foresees two gradual steps for phasing out low and medium efficiency ballasts. The first steps took place in year 2002 and phased out low efficiency magnetic ballasts (class D). The second steps took place in November 2005 and phased out Class C ballast representing the largest shared of the market. The EU Directive 2000/55EC aims to reach a market transformation by 31.12.2005 with the following values:
- • class A ballast 55%,
- • class B and C (sold until 01.11.2005) ballasts 45%.

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Recommended policies (1)

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- Launch a European promotion campaign to introduce one additional CFLs per household, to be installed in a place with long burning hours (more than 2 hours per day). This measure will be effective in most Member States and household as there are still a number of lighting points with long burning hours not covered by CFLs even in countries with a high CFLs penetration. The campaign could build on existing national and regional efforts and campaign, and could be linked to the climate change and security of supply issues, and in particular to the possible postponement of new power stations and transmission lines, an issue which is strongly felt by citizen at local level. It is also very important that in such campaign only high quality CFLs are promoted for example CFL, which meet the requirement of the European CFL Quality Charter.

- Further reduce the CFL purchasing price. Although the price of CFL has significantly decreased over the years, there is still a substantial price difference between CFLs and GLS lamps, especially for high quality CFLs. There are different ways to reduce the price gap. First the introduction of lower VAT rates for CFLs, and increased VAT rates on GLS. Second important methods are utilities incentives, rebates, and free give away, as part of DSM obligations, wire charges, and White Certificates. In particular an open White Certificate Scheme could allow also other market actors (e.g. ESCOs, lamp manufacturers, retailers) to subsidise the CFLs and in such a way get certified energy savings to sell in the certificate market. Suppliers and distributors would be still in a better position, as there could be cost recovery mechanisms or the programme cost could be introduced in the electricity price.

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Recommended policies (2)

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- Introduce minimum efficiency requirements for lamps. This option would be possible in the frame of the new European Eco Design Directive (EuP). However this would be a rather drastic option, as lamps not meeting the efficiency requirement would be phased out of the EU market. The efficiency requirement could be gradually strengthened over time, at the beginning for example phasing out only the low efficiency incandescent lamps. The initial threshold could be set at around 20 lm/W (allowing the best halogen lamps and the new LEDs) and gradually increase toward 50 lm/W (to be met only by fluorescent and other discharge technologies, and soon also by LED lighting).

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Recommended policies (3)

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- Introduce 'ban' on sales of high wattage torchieres. Very high wattage halogen lamps are increasing popular lighting fixtures in the residential sector, in particular the upright torchiere. These luminaires very often use lamps up to 300 W. A ban on sales of torchiere above certain wattage (e.g. 150 W) could be introduced in the frame of the EuP Directive. CFL based torchieres with the same lighting output as halogen based torchieres already exist in the market. To facilitate the introduction of the future proposed ban, rebate programmes for the CFL based torchieres should be introduced using the same mechanisms described in the point 2 above. In addition the ban could be introduced in advance by all public administrations in all levels, through their procurement specifications.

- Introduce more energy efficient dedicated fixtures. In the long term the best solution is to have in households all lighting fixtures, which can host only an efficient light source. At the present efficient light sources are pin based CFLs and some new low wattage metal halide lamps, in the near future also LEDs will be suitable for high efficiency dedicated fixtures. A first important step has been achieved with the European Design Competition "Lights of the Future", which has created awareness for the issue in luminaire manufacturers and designers, and to a limited degree on end users through the associated exhibitions in major lighting fair. Dedicated luminaires shall be supported in the market, mainly through rebate programmes, funded through the above described mechanisms. In the UK a new scheme has been introduced DEELS. – Domestic Energy Efficiency Lighting Scheme. The basic principle of DEELS is to retail energy efficient luminaires at the same price as the GLS equivalent luminaires. Another important mechanism to foster the introduction of dedicated luminaires is through the use of building codes. Since 2001 the UK requires on average three internal fixed fittings (efficiency > 40lm/W) plus one external fixed fitting (efficiency > 40lm/W, alternatively lighting controls) in new built dwellings. Also public procurement could further promote the use of dedicated fixture in social housing.

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Recommended policies (4)

- **Support additional R&D activities in lamps.** As already discussed new and innovative lighting technologies will change the residential lighting equipment. Beside smaller wattages induction lamps, already available, and metal halide lamps, offering high efficiency, newer fluorescent lamp such as cold cathodes and T1 fluorescent lamps are or will be soon available for the residential sector. In addition LEDs promise a new lighting revolution. However LED needs still R&D support before being able to reach or overcome the efficiency of present fluorescent lighting, at similar or lower cost. It is important that national governments and the EU institutions support lighting efficiency R&D projects, including future light sources for the residential sector.

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Draft 'Preparatory Study for Eco-design Requirements of EuP's in Office Lighting'

- General:
  - Target date for final report on office lighting = 15 June 2007
  - These are draft results, for final version please consult http://www.eup4light.net
- In chapter 6 (6.3) and 7 (7.4):
  - **(O)LED's are described as BNAT for office lighting** (= Best Not Yet Available Technology) **in chapter 6.**
  - **Identified: could contribute to further improvements** (update needed if more info becomes available) **in chapter 7.**

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Draft 'Preparatory Study for Eco-design Requirements of EuP's in Office Lighting'

In chapter 8 (policy analysis),actual draft proposed recommendations by Vito :

- Generic Eco-design requirements on the supply of information - for all indoor luminaires and ballasts with Linear and Compact (non integrated) Fluorescent lamps:
  - *- CEN flux code*
  - *- Ballast efficiency*
  - *- Luminaire Efficacy Ratio (LER)*
  - *- Luminaire light distribution class indicator* (to be elaborated)
- Generic Eco-design requirements on the supply of information for fluorescent lamps

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Draft 'Preparatory Study for Eco-design Requirements of EuP's in Office Lighting'

- Specific Eco-design requirements for all indoor luminaires and ballasts with LFL and CFL-ni lamps:
  - *Increase efficacy and reduce mercury of fluorescent lam*
  - *Increase ballast efficiency (adjustment of CELMA-values according to current technology)*
  - *Maximum stand-by losses for ballasts*
  - *Increase Luminaire Maintenance Factor (LMF)*
  - *Increase optic efficiency by increasing luminaire efficacy (LER)*

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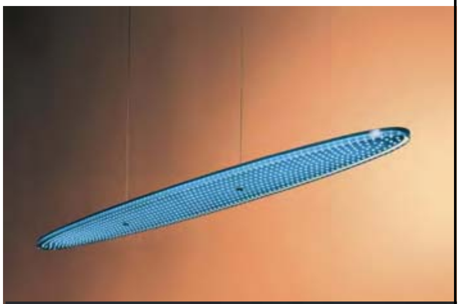
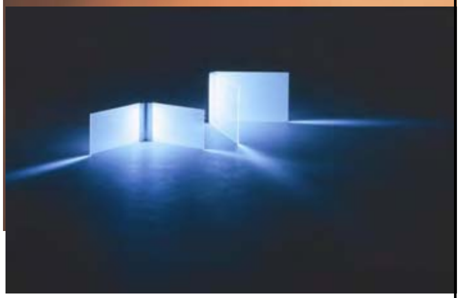
Conclusions

- Lighting is an important energy consumption in the residential sector with large, cost effective and quick energy savings in lighting. The total saving potential is about 20% or 18 TWh;
- Increased CFLs penetration is the most important action, by promoting them and by further reducing the price (White Certificates);
- Mandatory standards, ban on halogen torchieres, and more dedicated fixtures are also needed;
- We still need support for R&D activities especially for new lighting technologies such as LEDs;





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Thank you

For more information look at:

http://energyefficiency.jrc.cec.eu.int/CFL/index.htm

or

contact me at paolo.bertoldi@ec.europa.eu

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The Market Outlook for High-Brightness LEDs in Lighting Applications

International Workshop on Status, Prospects and Strategies for LEDs in General Lighting
May 3-4, 2007

Robert V. Steele
Strategies Unlimited

1

Outline

- Introduction
- HB LED Markets
- Lighting
- Outlook

2

HB LED Market Analysis

- Market is worldwide in scope
  - Main production and consumption are in US, Europe, Japan, Taiwan, S. Korea, China, SE Asia
- Market analyzed in terms of packaged devices (lamps, SMDs, multichip, high-power packages)
- Materials include InGaAlP (red-orange-yellow) and InGaN (blue, blue-green, green, white)
  - Higher performance, "qualified" devices
- Market segmented and sub-segmented by applications that have similar functionality

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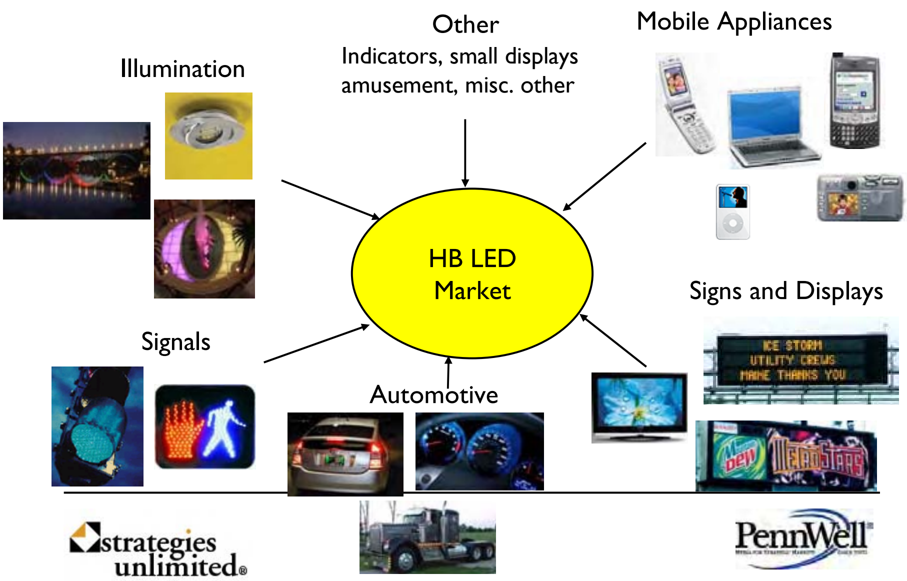
HB LED Application Segments



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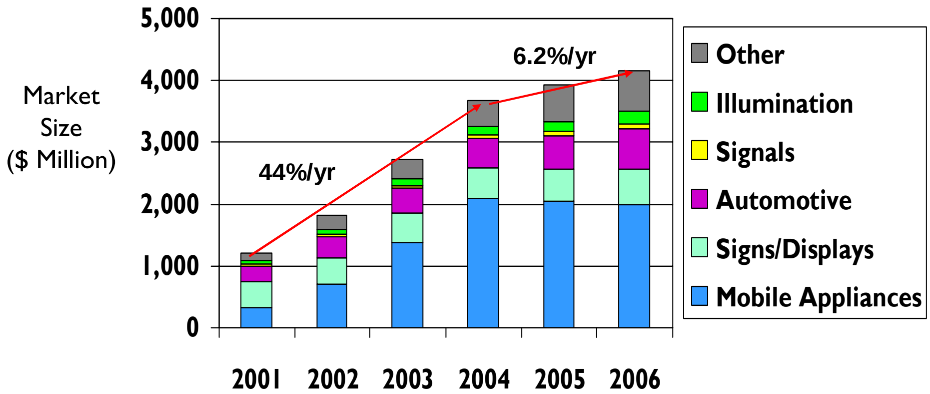
Outline

- Introduction
- HB LED Markets
- Applications
- Lighting
- Outlook

HB LED Market Trends

- Market continued its "slow growth" phase in 2006 – similar patterns to 2005
- Overall market growth was 6% to $4.2 billion
- Heavily influenced by ongoing decline in mobile phone market
- Other applications continued to have attractive growth rates
- Substantial ASP erosion across many product types

Recent Market History



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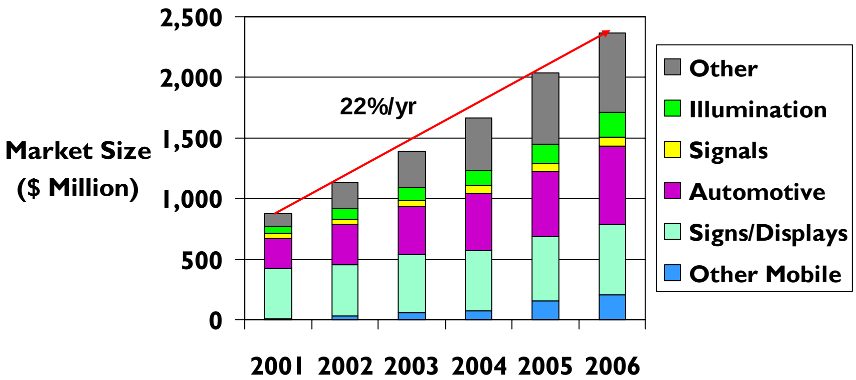
Market Growth Without Mobile Phones



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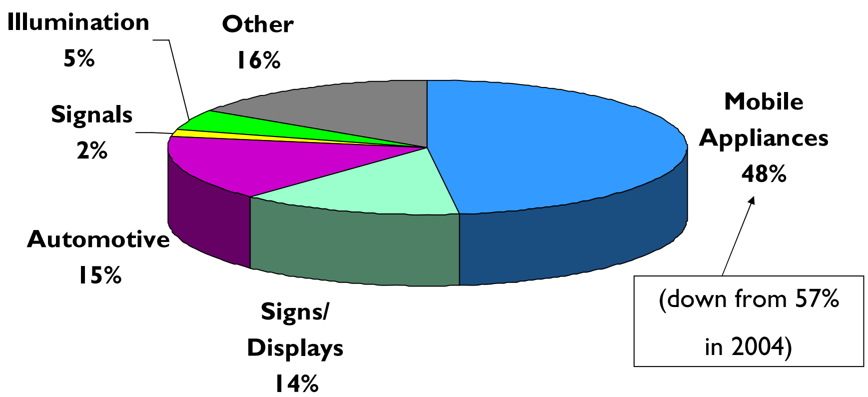
2006 Market by Application



Total: $4.2 Billion

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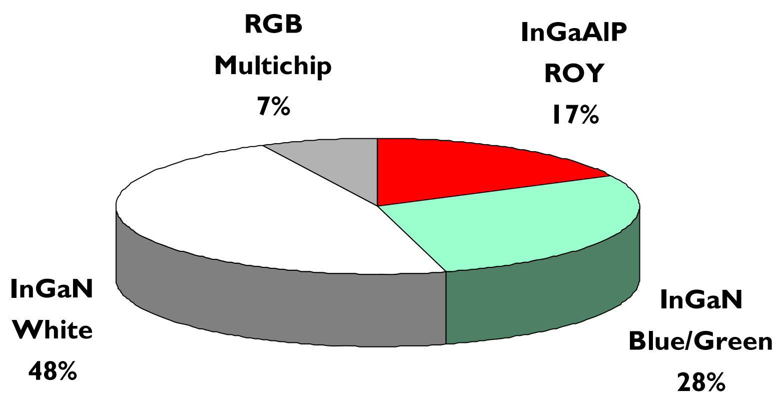
2006 Market by Color



Total: $4.2 Billion

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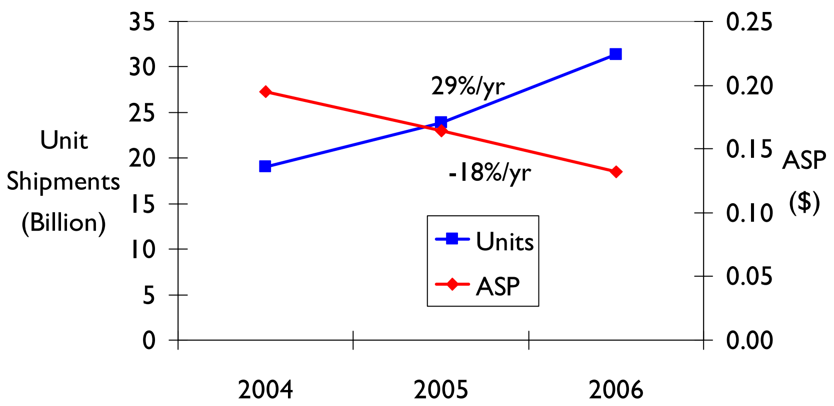
HB LED Units and ASPs



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Outline

- ❑ Introduction
- ❑ HB LED Markets
- ❑ Lighting
- ❑ Outlook

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Solid-State Lighting Market

- The use of HB LEDs for lighting is currently the fastest growing application
- The market is highly fragmented, encompassing many niche applications
  - The majority of applications are for colored (R,G,B) light
  - General illumination applications are starting to emerge
- Hundreds of companies worldwide are participating at the luminaire or fixture level
  - Strategies Unlimited has identified and described approximately 300 such companies, but there are more
  - Participants range from start-ups to the world's largest lighting companies

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HB LED Lighting Market

- The 2006 market for HB LEDs used in lighting was $205 million
  - Architectural is the largest
- Growing at around 37% per year – the highest of any HB LED application
- Projected to reach ~$1 billion in 2011
- Majority of applications use RGB today, but white will increase to more than 60% of the market by 2011

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Status of SSL Fixture Industry

- Many small companies dedicated to SSL; high level of LED expertise
- Many large and medium lighting companies, with some interest in SSL, offer a few products
  - Most lack in-house LED expertise
  - Rely on outside consultants for design, prototyping
- Volumes are small and costs are high, independent of high cost of LEDs
- Products in the market are highly variable in terms of quality

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SSL Market Development

- Most product and market development is being carried out by small, specialized companies
  - With a few exceptions, e.g. Philips Lighting, Zumtobel
- Generally, large lighting fixture company interest is modest (but interest is growing)
  - In-house LED expertise is minimal
  - European companies moving faster than US
- Established lighting companies control the access to large volume sales and distribution channels and customers

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SSL Market Drivers

- Visual appeal
  - Saturated colors, nearly point source of light, design flexibility
- Long lifetime, robust
  - Applications with high maintenance costs
- Compact form factor
- Lack of radiated heat or UV
- Low-voltage operation
- Energy efficiency
  - Colors, low wattage applications (e.g. battery and solar powered), low temperature operation
  - Improving rapidly

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10 Significant Near-Medium Term Applications

- Architectural
- Channel letter/contour lighting
- Consumer portable (e.g. flashlights)
- Residential
- Machine vision
- Retail display
- Entertainment
- Safety/Security
- Outdoor area
- Off-grid (generally solar-powered)

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Interesting Emerging General (White) Lighting Applications

- Retail Display
  - Lumination (GELcore)
  - Stylmark
  - OptoLum
  - MAG-LED
  - Nualight
  - i-LED
  - Color Kinetics
  - Bartco
  - Matsushita Electric Works
  - Philips
- Residential
  - Permlight
  - LED Lighting Fixtures (LLF)
  - Lemnis
  - Progress
  - Renaissance
  - Bruck

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Retail Display Lighting

- White LEDs are being used to provide attributes that are advantageous for certain types of products:
- High-end retail (e.g. designer label branded stores)
  - "High-tech" look; interesting effects; design flexibility
- Cosmetics
  - Lack of radiated heat from source
- Jewelry
  - Sparkling appearance from point light source; compact; low heat; long life
- Refrigerated display cases
  - More efficient than linear fluorescents at low temperatures; rapid start-up; long lifetime

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Retail Display Lighting Examples

Source: Hera GmbH

Source: Nualight

Source: MAG-LED

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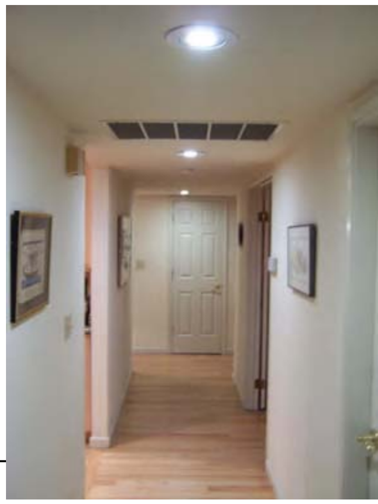
LED Residential Lighting



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Refrigerated Display Case Success Story

- Wal-Mart adoption of LED refrigerated display case lighting from GELcore was the SSL "story of the year"
- Installing in all new Sam's Club and SuperStores from Dec. 2006, ~300 per year in US
  - Part of the Wal-Mart's "green" strategy
- Drivers are energy and maintenance savings
  - Can use occupancy sensors to turn off lighting during low traffic periods (impossible with fluorescent due to slow start-up)
- Other supermarket chains are likely to follow Wal-Mart's lead

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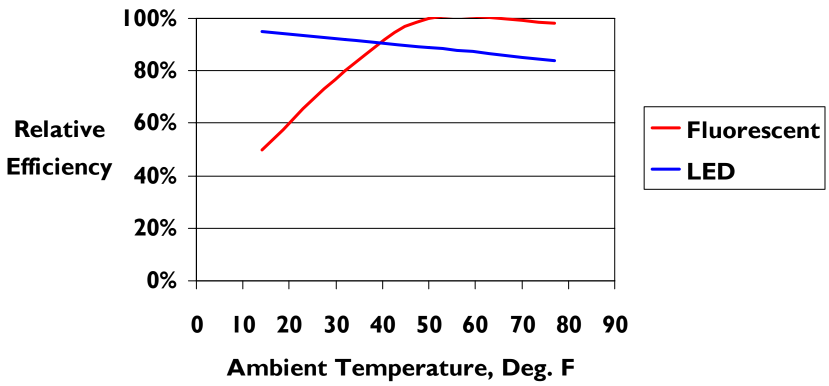
Linear Fluorescent vs. White LED Relative Efficiency



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Opportunities for SSL

- Offer a unique lighting solution
- Create an aesthetically pleasing lighting environment
- Deliver value (on a cost-of-ownership basis)
- Provide lighting products adapted to unique physical environments
- Save energy; comply with regulatory requirements (e.g. Title 24 in California)

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Challenges for SSL

- High initial cost
- Other alternatives for energy efficiency
- Consistency of color/binning issues
- Need to provide a complete lighting solution with ease of installation
- Adapt to standard electrical interfaces and controls
- Realistic claims of performance
- Development of standards
- Need widespread base of lighting fixture designers and engineers who understand LEDs
- Need for high-efficiency light engine/fixture design

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Essential Design Principles for LED Light Engines

1. Don't waste photons
2. Don't waste electrons
3. Be cool

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Examples

Efficient Design

Start with 70 lm/W 1-W white LEDs (at 25 °C junction temperature)
Assume: 90% electrical efficiency; 90% optical efficiency; operate at 65 °C junction temperature

Light engine efficacy = 70 x 0.9 x 0.9 x 0.85 = **48 lm/W**

Inefficient Design

Start with 70 lm/W 1-W white LEDs (at 25 °C junction temperature)
Assume: 80% electrical efficiency; 80% optical efficiency; operate at 100 °C junction temperature

Light engine efficacy = 70 x 0.8 x 0.8 x 0.75 = **34 lm/W**

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Outline

- Introduction
- HB LED Markets
- Lighting
- Outlook

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LED Lighting Market Outlook

- Niche lighting applications will continue to grow
- General illumination (e.g. white light applications) will become increasingly important
- Presumes continuing improvement in white LED price/performance
  - And luminaire performance!
- Presumes substantial marketing efforts to penetrate the conventional lighting market
  - Penetration will proceed gradually – application by application
- Overall forecast 37% CAGR to ~$1 billion in 2011

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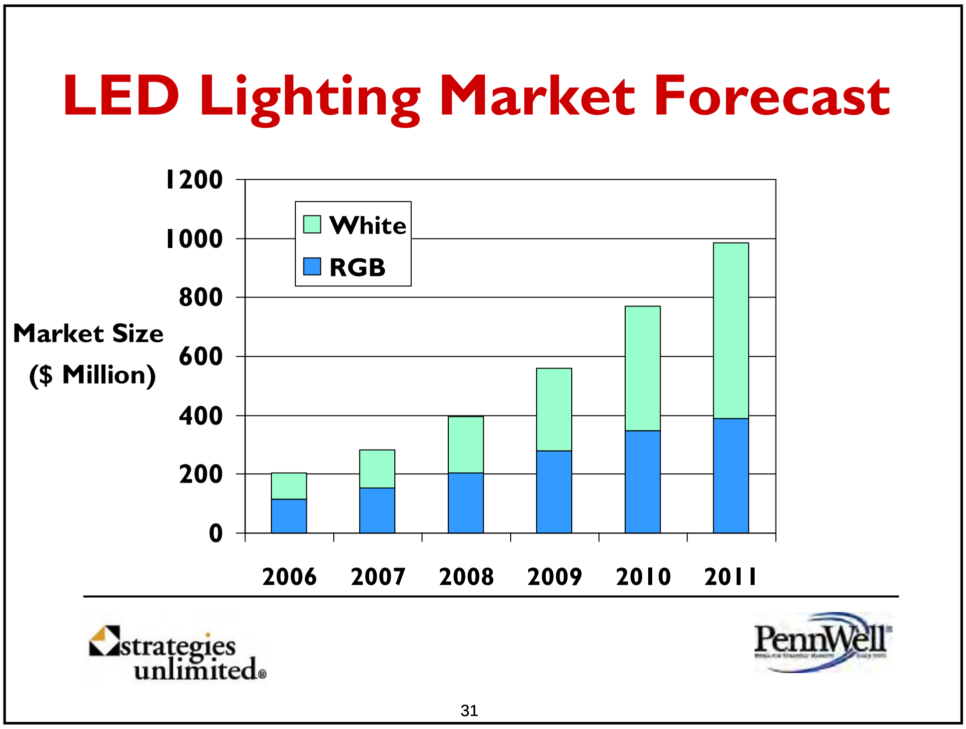
LED Lighting Market Forecast
1200
1000
800
600
400
200
0
Market Size
($ Million)
White
RGB
2006
2007
2008
2009
2010
2011
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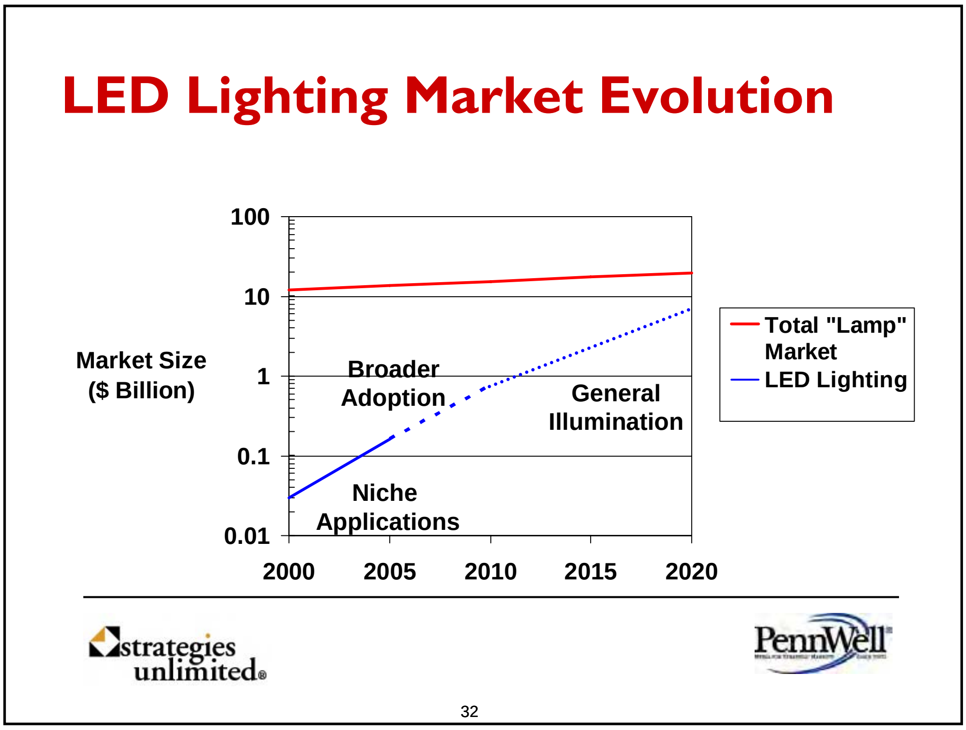
LED Lighting Market Evolution
100
10
1
0.1
0.01
Market Size
($ Billion)
Broader Adoption
General Illumination
Niche Applications
2000
2005
2010
2015
2020
Total "Lamp" Market
LED Lighting
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Thank you!

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Update on Recent Technical Developments in the LED Marketplace

Tim Whitaker

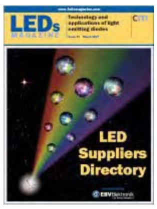
Editor, *LEDs Magazine*

tim.whitaker@ledsmagazine.com

www.LEDsMagazine.com

LEDs Magazine

1. **Website**
   – Daily news & products, resources, archives
2. **Email newsletter**
   – Weekly news update
3. **LEDs Magazine**
   – Bimonthly magazine, in-depth articles and analysis
4. **LED Suppliers Directory**
   – Printed annual guide



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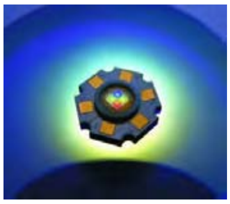
LED Performance

- Continuous, ongoing development
- Efficacy continues to improve
  - approaching 100 lm/W in production
  - driven by mobile phone market, also backlighting, illumination
  - high-power LEDs less efficient



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LED Performance

- Thermal management is a key issue
  - Heat decreases LED output, life
  - Continuing efficiency improvements are crucial
  - Some LEDs more tolerant to higher temperatures
- Optical, electrical (driver) issues also important

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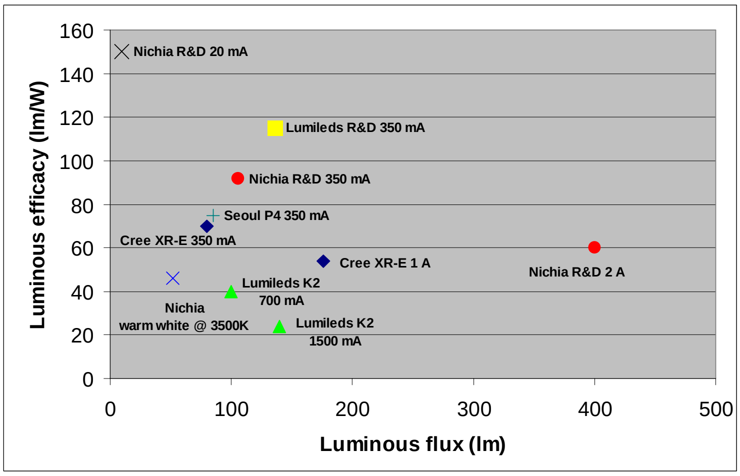
Flux and Efficacy



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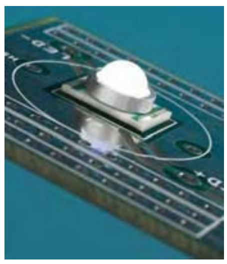
Cree XLamp – 80 lm package

Cool white:

- 80 lm at 350 mA, 70 lm/W (typical figures)
- 95 lm, 85 lm/W (best figures)
- Up to 160 lm at 700 mA



Warm white:

- 2600K: 65 lm (56 lm/W) at 350 mA
- 110 lm (45 /m/W) at 700 mA

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Warm White LEDs

- Lower efficacy than cool white
  - new phosphors required
- Color shift larger than cool white
  - phosphor degradation??
  - heating effects??

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What do these numbers mean?

- "Nichia reports 150 lm/W white LED"
  - Small chip driven at 20 mA
  - Light output approx. 9 lumens
  - R&D result, not mass production
- 100 lm/W devices in production soon
- Indicative of future progress

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What do these numbers mean?

- Are numbers R&D or production?
- In production, are they typical values, best possible, or minimum guaranteed?
- Do the devices have high reliability, or exhibit significant color shift over time?

Luminaire Efficacy

- LED efficacy does not equal luminaire efficacy
- Luminaire efficacy likely to be at least 20% lower
  - Electrical, optical losses
  - Worse for poor luminaire designs

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LED Measurements

- LED datasheet measurements are made:
  - Instantaneously
  - At LED junction temperature of 25 ºC
- In real-life applications/luminaires:
  - LED T_J will be higher (= lower output)
  - Luminaire output settles to steady-state value after ~2 hours

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Campaign for Real Data

- Avoid bad data
  - Creates confusion
  - Reduces credibility
- Develop standards
- LED system performance has multiple trade-offs:
  - lumen output vs. efficacy vs. current vs. temperature vs. lifetime vs. CRI…

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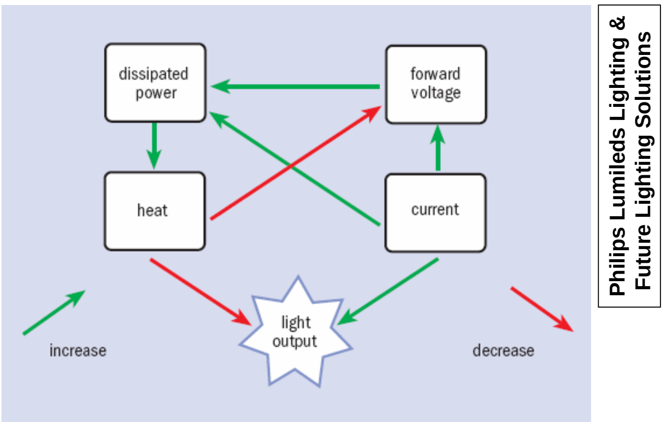
Usable Light in a Real Application



- Multiple trade-offs, complex interaction of parameters determines actual light output

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Key Data Points

- Efficacy (lumens/watt)
- Input power (current and voltage)
- Lumens
- Chip size
- Correlated color temperature (CCT)
- Color rendering index (CRI)
- Lifetime/reliability
- Was testing at thermal equilibrium?
- Was third-party testing involved?

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Standards Development

- USA: multiple standards in development
  - Chromaticity (color)
  - Luminous flux
  - Lumen depreciation (lifetime)
  - Definitions of solid-state lighting
  - Color quality
  - Photobiological safety (e.g. eye safety)
  - Electrical safety

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Standards & Related Work

- Energy Star will shortly include LEDs
  - Voluntary labelling program for energy-efficient products
- Underwriters Laboratories (UL)
  - New documentation covering LEDs
- DOE SSL program – commercialization
  - SSL luminaire testing program
  - SSL luminaire evaluation in “real” situations

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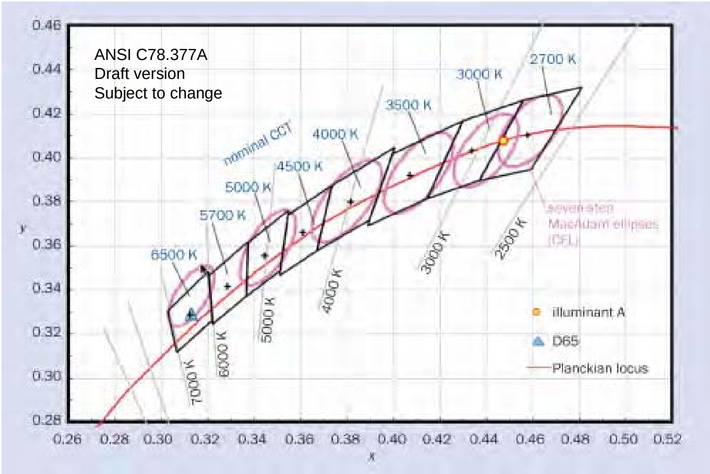
White LED Chromaticity



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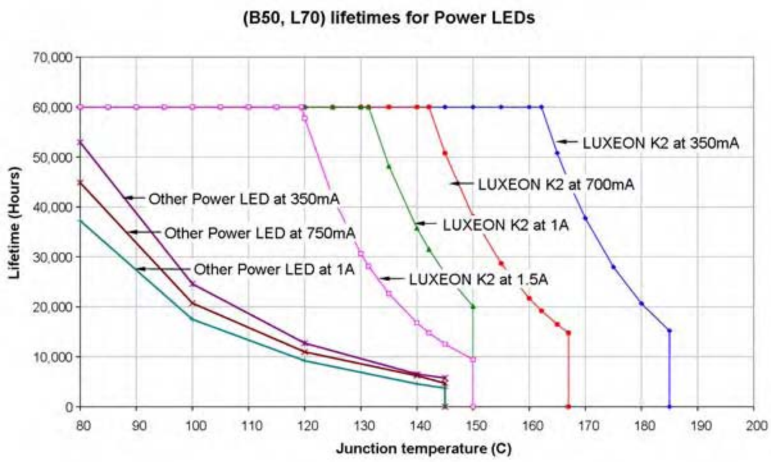
Lifetime data



- L = lumen maintenance, B = “failure”

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State-of-the-art?

- LED Lighting Fixtures Inc
  - 6-inch downlights
  - Warm-white 2700 or 3500 K
  - 650 lm at 11 W wall-plug power
  - 60 lm/W efficacy (wall-plug)
  - Color rendering index 92
  - Performance measured by third party

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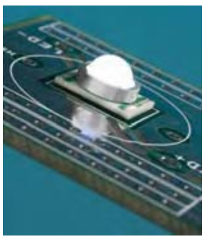
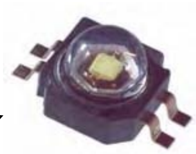
Trends in Power LEDs

- Optimize for $/lumen
- Optimize for lm/W
- Optimize for lumen output

Single chip power LED package





Robust packaging enables higher currents (Luxeon K2)

Smaller form factors (Luxeon Rebel)

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Multi-chip packages

- Multiple small chips in single package
  - 24 chips and 245 lm per strip, 70 lm/W

- Multiple large area chips

- Chip-on-board array of small chips

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Power LED Development

Packaging	Device (chip) design	Epitaxy & materials
• Reliability • PC LEDs: white light distribution		
• Heat extraction		
	• Extraction efficiency • High-current operation • Low forward voltage	
		• Internal quantum efficiency (IQE)

Features requiring improvement

Philips Lumileds

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Patents – RGB LED Lighting

- Color Kinetics patents in US cover basic technology of using PWM with LEDs
  - Highly contentious
  - Situation better in Europe
- CK has licensed widely e.g. Martin, Super Vision, Ford
  - Patent dispute with TIR (being acquired by Philips)
- Other companies developing alternative technologies e.g.
  - Artistic License
  - Carpenter Decorating/NXP

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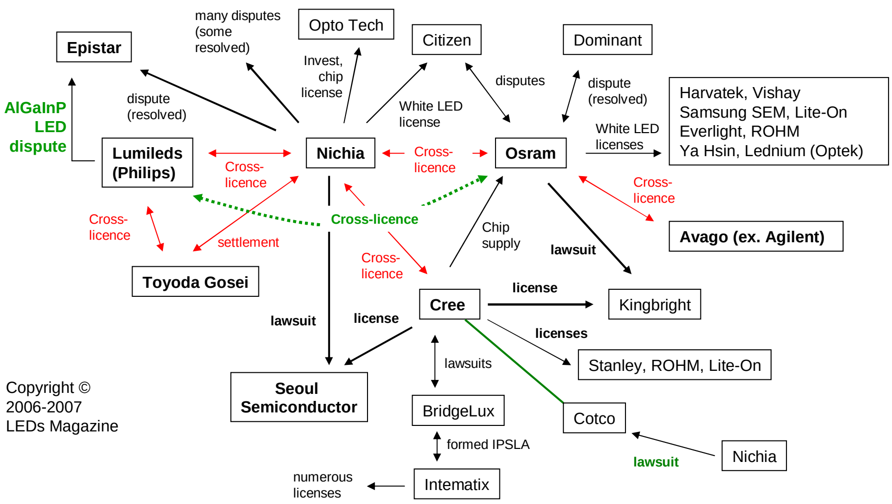
The White LED Minefield



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Penetrating the Lighting Industry #1

- Don't make over-ambitious claims!!
  - LEDs are not the answer for every lighting problem/situation
- Regulations & standards
  - USA: Energy Star, luminaire testing
- Raise customer awareness/acceptance
  - Learn lessons from CFL history

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Penetrating the Lighting Industry #2

- Improve performance of warm white
  - Opens up indoor lighting applications
- Consistency & control
  - Process improvements to improve/eliminate binning
  - Color mixing and optical/thermal feedback for precise color control
- Increase performance, reduce cost
  - Cost per lumen still too high

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Conclusions

- Multiple application areas for LEDs
- Performance gains continuing
  - Many applications crucially dependent on consistency, control…and lower cost!
- Support from numerous national/regional programs
- Strong need to develop standards

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Vertical Integration

	Philips	**Osram**	**Zumtobel**	**GE**
LEDs	**Lumileds Lighting** & Future Lighting Solutions	**Osram Opto Semiconductors**	- Lexedis (Tridonic + **Toyoda Gosei**) -**Tridonic Optoelectronics**	Partnership with **Nichia**
Modules, controllers, systems	Philips Solid State Lighting	Osram LED Systems	- TridonicAtco - Ledon Lighting	GE Lumination
Luminaires	- Philips Lighting - TIR Systems - PLI		- Zumtobel -Thorn	GE Lighting

- VS Opto part of MEW
- Cree distributed worldwide by Arrow

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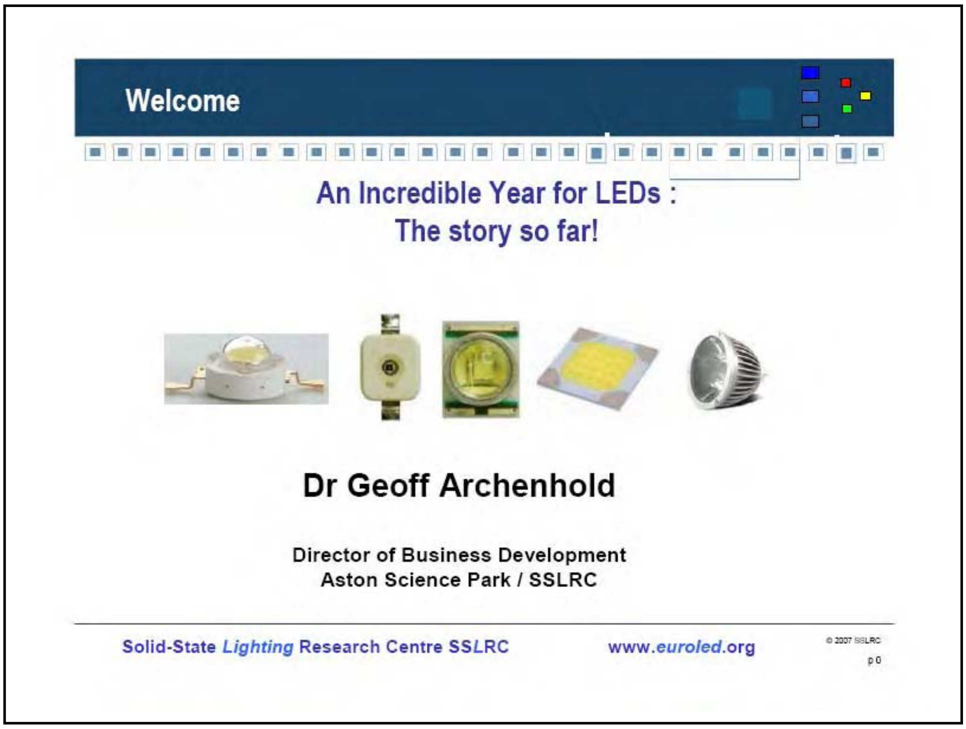
Welcome
An Incredible Year for LEDs :
The story so far!
Dr Geoff Archenhold
Director of Business Development
Aston Science Park / SSLRC
Solid-State Lighting Research Centre SSLRC
www.euroled.org
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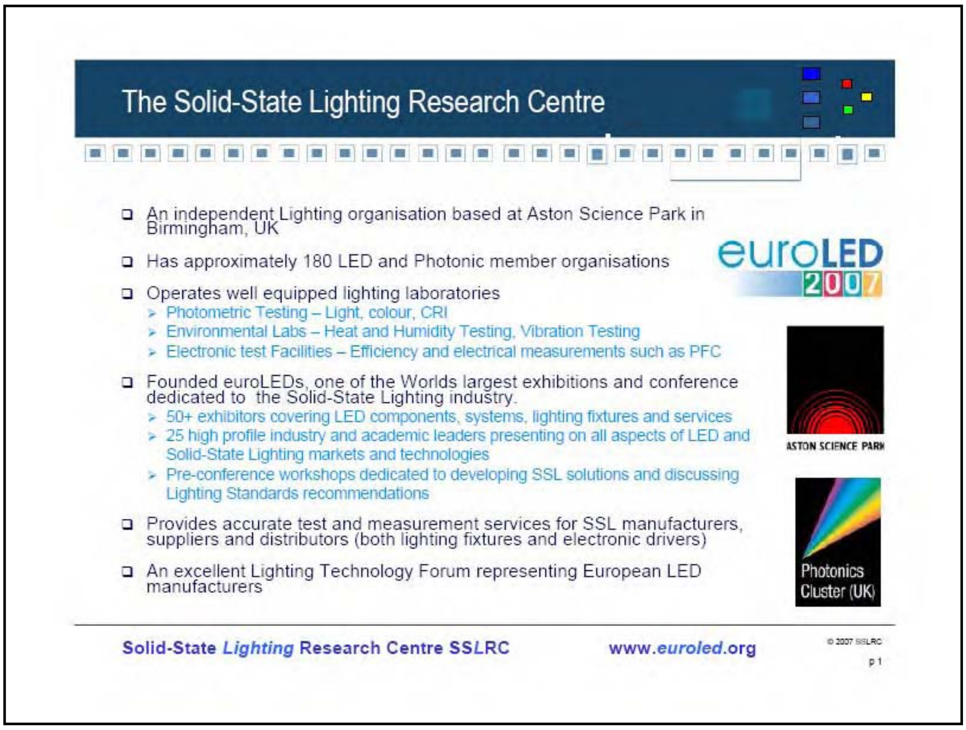
The Solid-State Lighting Research Centre
An independent Lighting organisation based at Aston Science Park in Birmingham, UK
Has approximately 180 LED and Photonic member organisations
Operates well equipped lighting laboratories
Photometric Testing – Light, colour, CRI
Environmental Labs – Heat and Humidity Testing, Vibration Testing
Electronic test Facilities – Efficiency and electrical measurements such as PFC
Founded euroLEDs, one of the Worlds largest exhibitions and conference dedicated to the Solid-State Lighting industry.
50+ exhibitors covering LED components, systems, lighting fixtures and services
25 high profile industry and academic leaders presenting on all aspects of LED and Solid-State Lighting markets and technologies
Pre-conference workshops dedicated to developing SSL solutions and discussing Lighting Standards recommendations
Provides accurate test and measurement services for SSL manufacturers, suppliers and distributors (both lighting fixtures and electronic drivers)
An excellent Lighting Technology Forum representing European LED manufacturers
euroLED 2007
ASTON SCIENCE PARK
Photonics Cluster (UK)
Solid-State Lighting Research Centre SSLRC
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Creating a Brighter Future

- **Remember the late 1980's?**
  - Environmentalism was in fashion and a slew of products proudly proclaimed their green credentials!
  - Reality : In a short space of time green credentials rapidly slipped down the business agenda!
- **Remember October 2006? – you should do!**
  - The Stern Review reported on the economics of climate change and the potentially catastrophic consequences.
  - Reality : It is rapidly becoming obvious that going green today is the only way to create a brighter future.
- **Why is their a difference?**
  - Sustainability is now being taken seriously by both consumers AND business!

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Creating a Brighter Future

- **The future without Solid-State Lighting?**

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Creating a Brighter Future

- **A few basic UK lighting statistics**
  - There are **~25.6** million UK Households in 2005
  - Total residential electricity consumption was **111.88 TWh**
  - Total UK residential lighting consumption was **17.9 TWh** or 16%
    - CO_2 Equivalent of driving a car **21,927,500,000** miles!
  - There are on average 20 lighting points per UK household
  - On average only 2 points utilise energy efficient lighting mainly consisting of Compact Fluorescents
  - The three most powerful lamps used in the home are ~65 Watts per lamp
- **Potential savings by adopting LED lighting**
  - Assuming that 25% of lighting points are converted to energy efficient light sources. (remember 2 lights are already EE)
  - Assuming that an LED light source achieves ~60 lm/W
  - The annual electricity saving would be approximately **2197 GWh**
    - Equivalent to running ~**8.3 million Playstation 2's for 1 entire year**
    - CO_2 Reduction equivalent of driving **2,691,325,000** car miles per year
  - Would generate a UK demand for **68.4 million** LED light sources

Conversion factor 1KWh = 0.441kg CO_2

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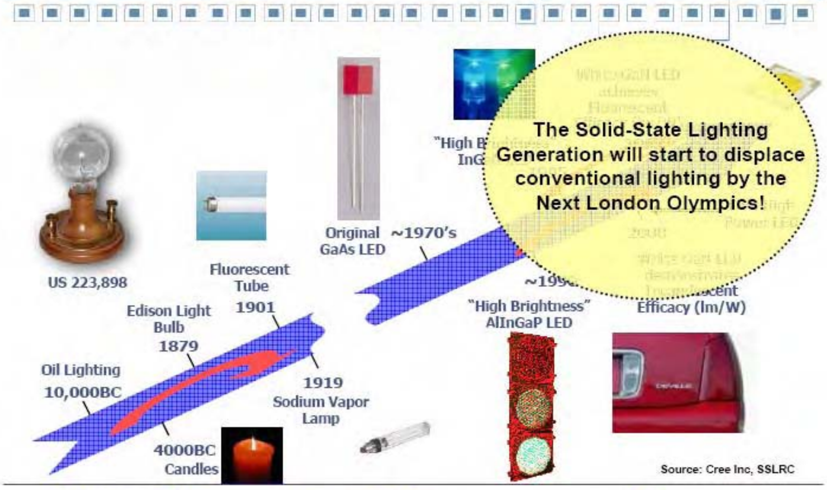
A Brief History of Lighting



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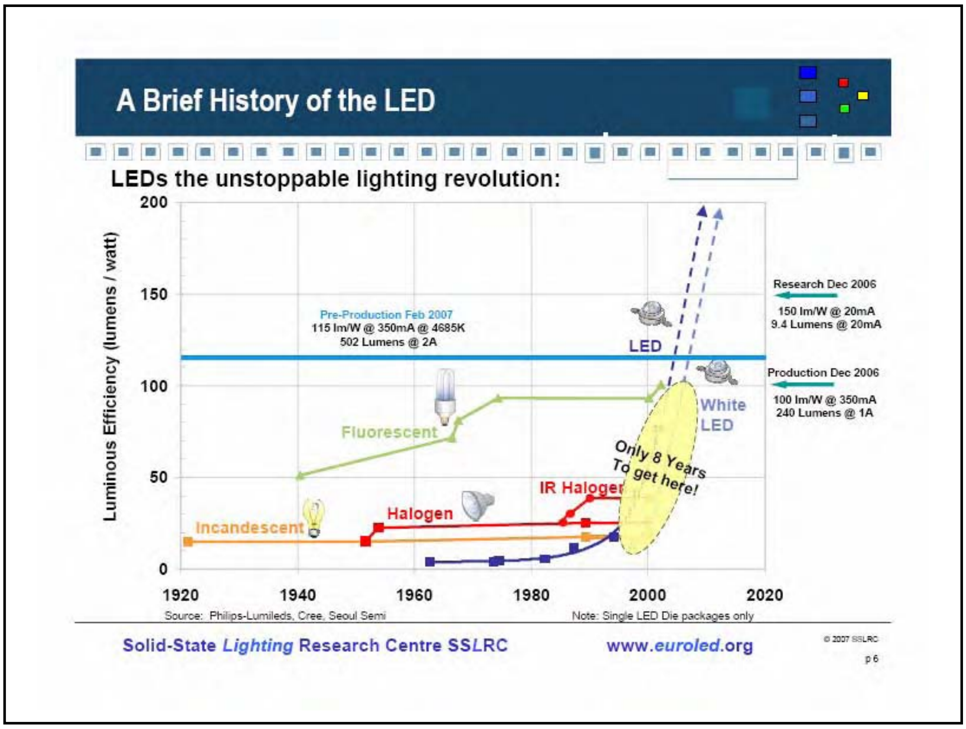
A Brief History of the LED
LEDs the unstoppable lighting revolution:
Luminous Efficiency (lumens / watt)
200
150
100
50
0
1920
1940
1960
1980
2000
2020
Pre-Production Feb 2007
115 lm/W @ 350mA @ 4685K
502 Lumens @ 2A
LED
Research Dec 2006
150 lm/W @ 20mA
9.4 Lumens @ 20mA
Production Dec 2006
100 lm/W @ 350mA
240 Lumens @ 1A
White LED
Fluorescent
Only 8 Years To get here!
IR Halogen
Halogen
Incandescent
Source: Philips-Lumileds, Cree, Seoul Semi
Note: Single LED Die packages only
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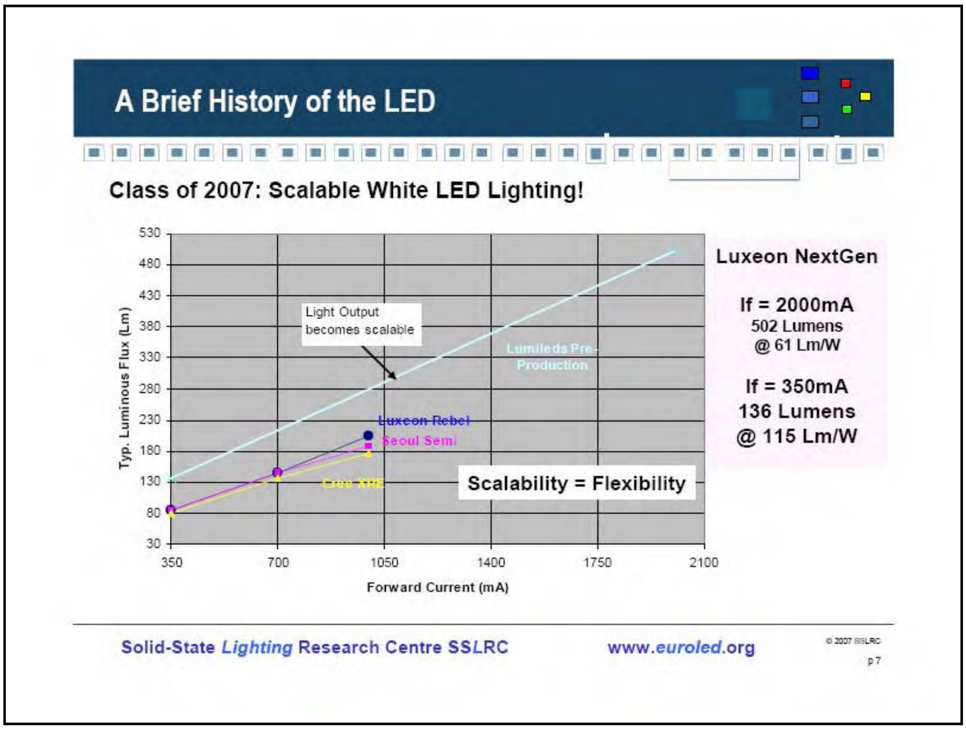
A Brief History of the LED
Class of 2007: Scalable White LED Lighting!
Typ. Luminous Flux (Lm)
530
480
430
380
330
280
230
180
130
80
30
350
700
1050
1400
1750
2100
Forward Current (mA)
Light Output becomes scalable
Lumileds Pre-Production
Luxeon Rebel
Seoul Semi
Cree XRE
Scalability = Flexibility
Luxeon NextGen
If = 2000mA
502 Lumens
@ 61 Lm/W
If = 350mA
136 Lumens
@ 115 Lm/W
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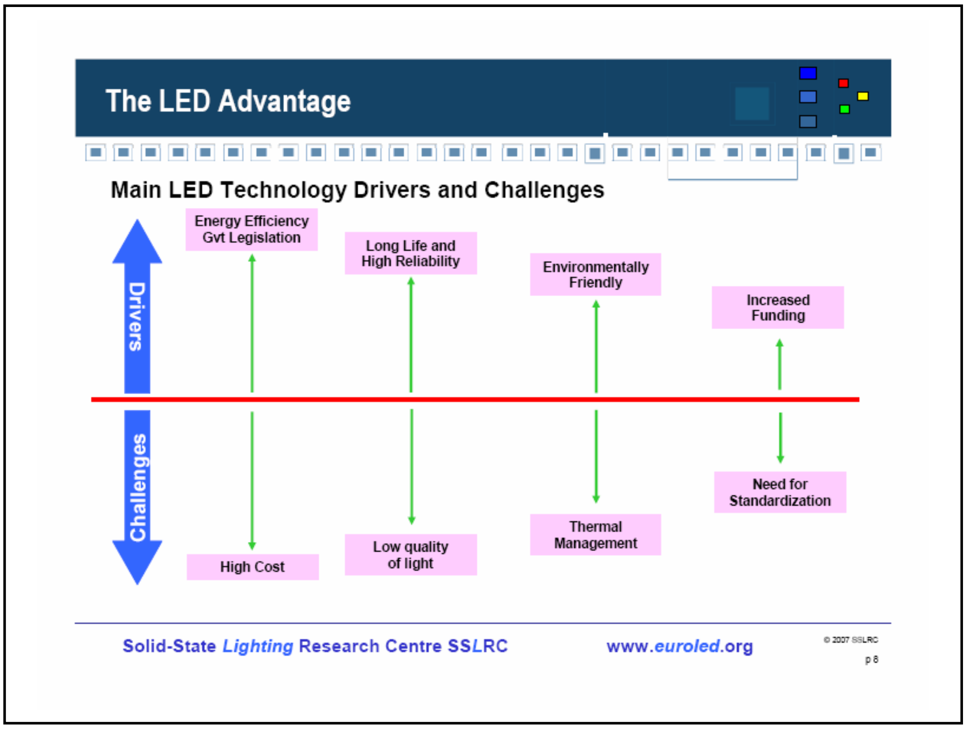
The LED Advantage
Main LED Technology Drivers and Challenges
Drivers
Challenges
Energy Efficiency
Gvt Legislation
Long Life and
High Reliability
Environmentally
Friendly
Increased
Funding
High Cost
Low quality
of light
Thermal
Management
Need for
Standardization
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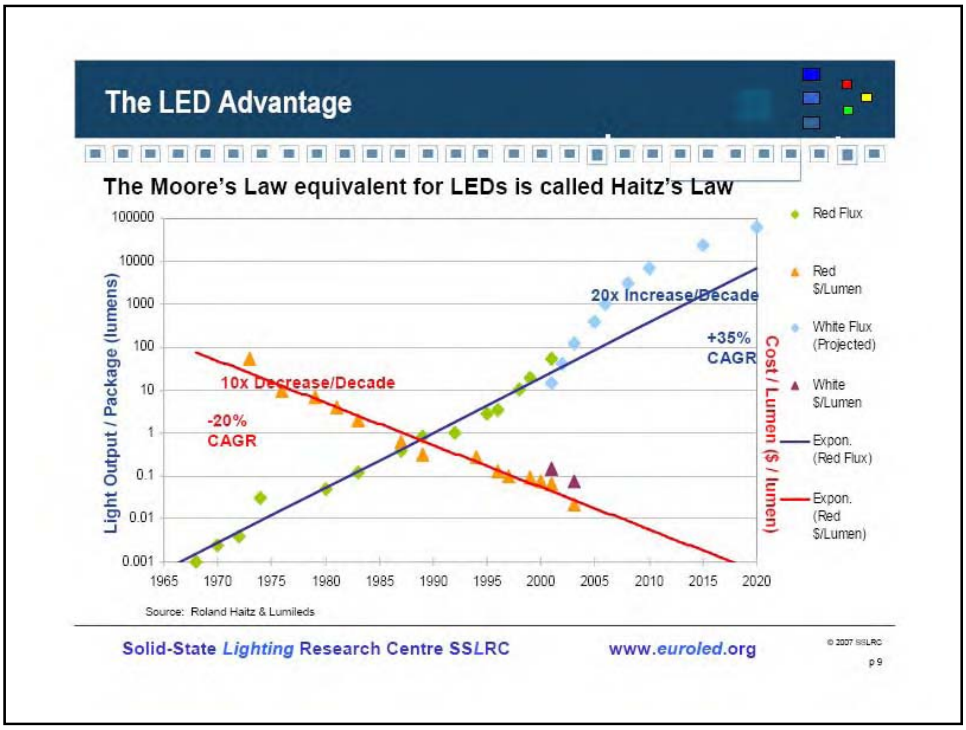
The LED Advantage
The Moore's Law equivalent for LEDs is called Haitz's Law
Light Output / Package (lumens)
Cost / Lumen ($ / lumen)
100000
10000
1000
100
10
1
0.1
0.01
0.001
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
20x Increase/Decade
+35%
CAGR
10x Decrease/Decade
-20%
CAGR
Red Flux
Red
$/Lumen
White Flux
(Projected)
White
$/Lumen
Expon.
(Red Flux)
Expon.
(Red
$/Lumen)
Source: Roland Haitz & Lumileds
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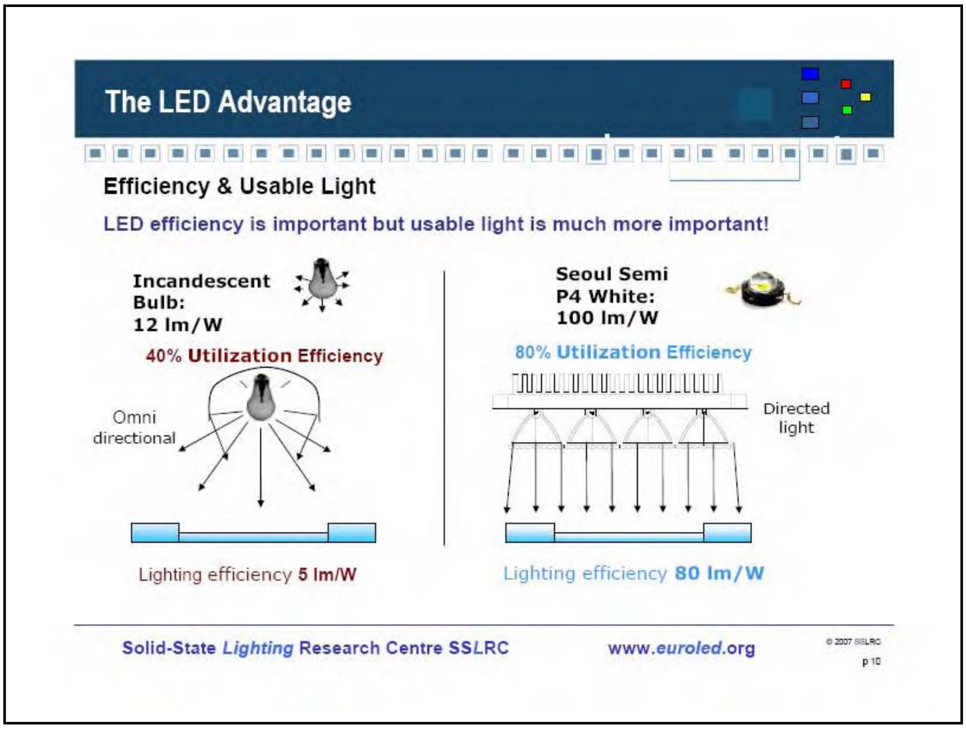
The LED Advantage
Efficiency & Usable Light
LED efficiency is important but usable light is much more important!
Incandescent Bulb: 12 lm/W
40% Utilization Efficiency
Omni directional
Lighting efficiency 5 lm/W
Seoul Semi P4 White: 100 lm/W
80% Utilization Efficiency
Directed light
Lighting efficiency 80 lm/W
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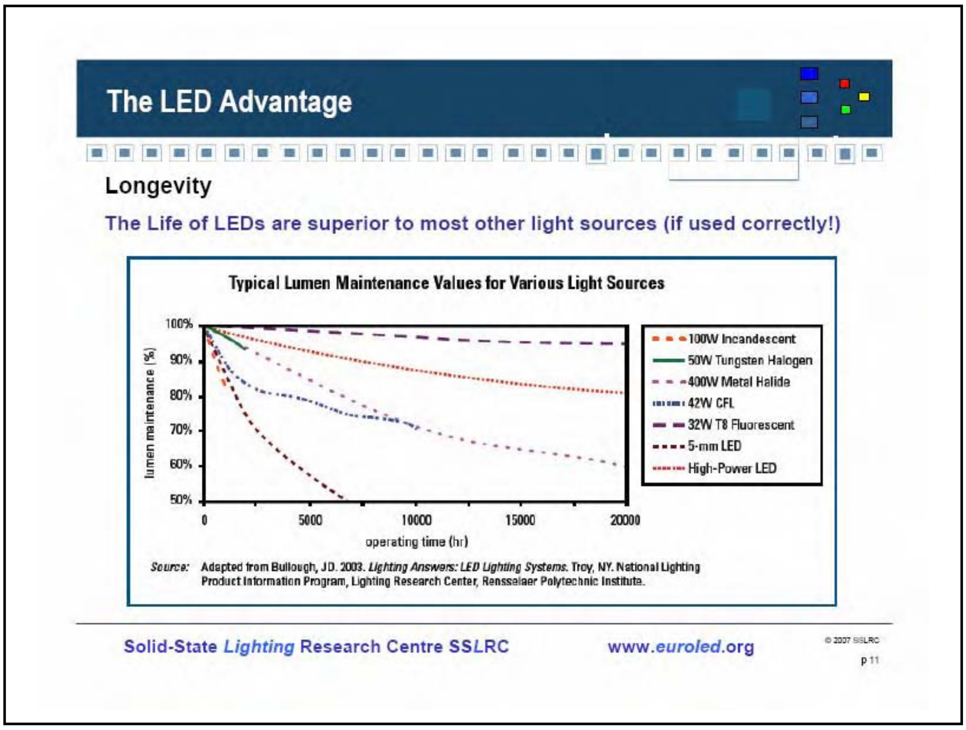
The LED Advantage
Longevity
The Life of LEDs are superior to most other light sources (if used correctly!)
Typical Lumen Maintenance Values for Various Light Sources
lumen maintenance (%)
100%
90%
80%
70%
60%
50%
0
5000
10000
15000
20000
operating time (hr)
100W Incandescent
50W Tungsten Halogen
400W Metal Halide
42W CFL
32W T8 Fluorescent
5-mm LED
High-Power LED
Source: Adapted from Bullough, JD. 2003. Lighting Answers: LED Lighting Systems. Troy, NY. National Lighting Product Information Program, Lighting Research Center, Rensselaer Polytechnic Institute.
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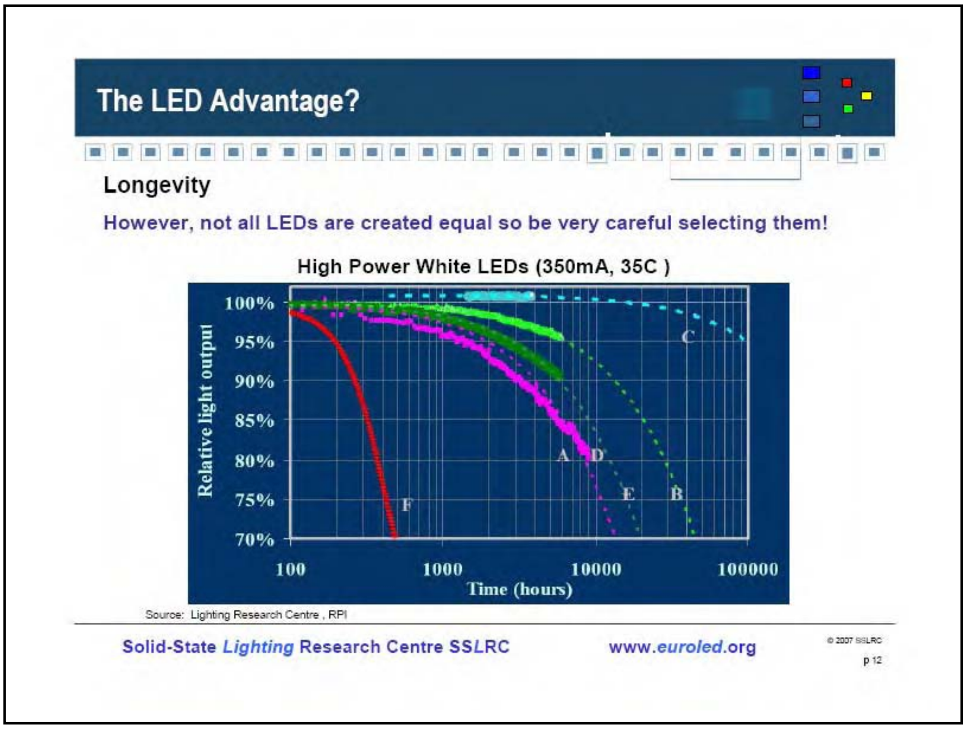
The LED Advantage?
Longevity
However, not all LEDs are created equal so be very careful selecting them!
High Power White LEDs (350mA, 35C)
100%
95%
90%
85%
80%
75%
70%
Relative light output
100
1000
10000
100000
Time (hours)
A
B
C
D
E
F
Source: Lighting Research Centre , RPI
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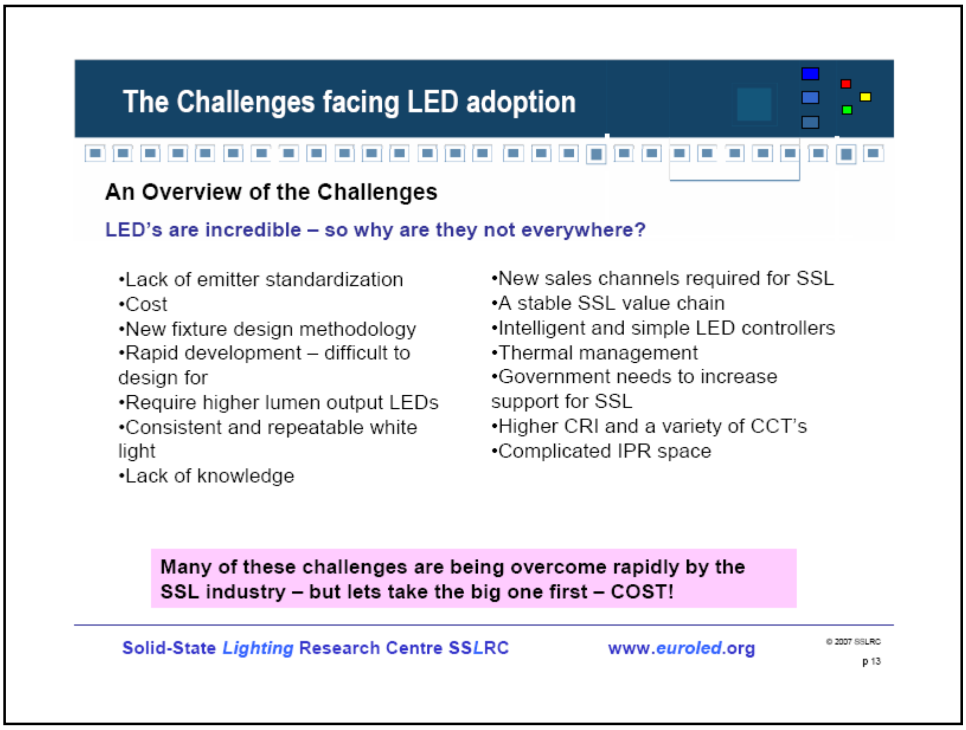
The Challenges facing LED adoption
An Overview of the Challenges
LED's are incredible – so why are they not everywhere?
•Lack of emitter standardization
•Cost
•New fixture design methodology
•Rapid development – difficult to design for
•Require higher lumen output LEDs
•Consistent and repeatable white light
•Lack of knowledge
•New sales channels required for SSL
•A stable SSL value chain
•Intelligent and simple LED controllers
•Thermal management
•Government needs to increase support for SSL
•Higher CRI and a variety of CCT's
•Complicated IPR space
Many of these challenges are being overcome rapidly by the SSL industry – but lets take the big one first – COST!
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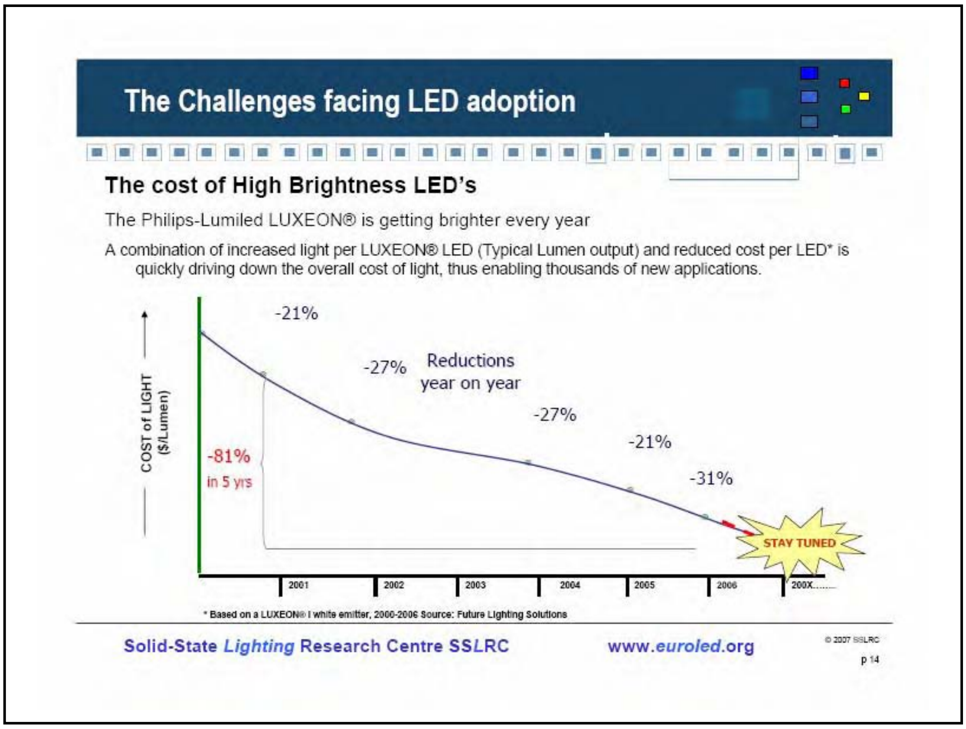
The Challenges facing LED adoption
The cost of High Brightness LED's
The Philips-Lumiled LUXEON® is getting brighter every year
A combination of increased light per LUXEON® LED (Typical Lumen output) and reduced cost per LED* is quickly driving down the overall cost of light, thus enabling thousands of new applications.
COST of LIGHT ($/Lumen)
-21%
-27%
Reductions year on year
-27%
-21%
-31%
-81% in 5 yrs
STAY TUNED
2001
2002
2003
2004
2005
2006
200X........
* Based on a LUXEON® I white emitter, 2000-2006 Source: Future Lighting Solutions
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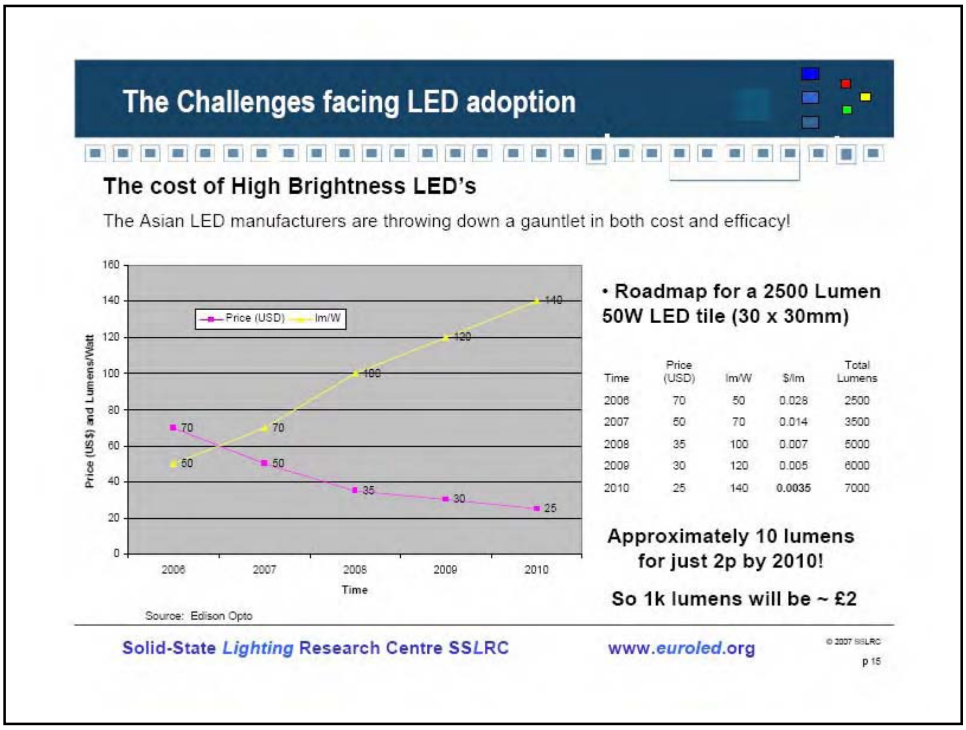
The Challenges facing LED adoption
The cost of High Brightness LED's
The Asian LED manufacturers are throwing down a gauntlet in both cost and efficacy!
Price (USD)
lm/W
Price (US$) and Lumens/Watt
Time
Source: Edison Opto
• Roadmap for a 2500 Lumen 50W LED tile (30 x 30mm)

Time	Price (USD)	lm/W	$/lm	Total Lumens
2006	70	50	0.028	2500
2007	50	70	0.014	3500
2008	35	100	0.007	5000
2009	30	120	0.005	6000
2010	25	140	0.0035	7000

Approximately 10 lumens for just 2p by 2010!
So 1k lumens will be ~ £2
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The Challenges facing LED adoption

Total System Efficiency

An LED fixture is more than just an LED it's a system!

LED Efficacy	50 lm/W P = 36W	50 lm/W P = 36W
+		
Fixture Efficacy	Optics 85% Heat 70%	Optics 85% Heat 70%
+		
LED Driver Efficacy	Driver 80%	Driver 88%
=		
Total System Efficacy	=(50*36)*0.85*.7*.8 = 856.8 Lm or 47.6%	=(50*36)*0.85*.7*.88 = 942.5 Lm or 52.4%

A higher efficiency LED driver makes a 5% difference to total LED system efficacy!

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The Challenges facing LED adoption

The Intelligent LED Driver

- **There are many driver techniques available to operate LEDs**
  - **Each driving technique has advantages and disadvantages.**

- Direct Current (**DC**) – Single colour but most efficient! (LRC)
- Pulse Width Modulation (**PWM**) – Multi colour
- Pulse Amplitude Modulation (**PAM**) – Multi colour
- Pulse Frequency Modulation (**PFM**) – Single colour
- Variants of all above

- **FACT**:
- Only poor LED fixture designs do not employ closed-loop feedback
- Closed-loop feedback is easier with some techniques than others!
- Generation 3 LED drivers include **I, T** & **colour feedback** control

- **REALITY**:
- Very few commercial drivers use any closed-loop feedback
- Majority of LED drivers are generation 1 or at best 2
- Few innovative options due to complex IPR space
- Currently, only one driver using RDM to remotely monitor fixtures.

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The Challenges facing LED adoption
A New Class of LED Driver
• High efficiency
• >85% for both AC/DC and LED driver stages
• Closed-Loop Feedback
• Monitor and reports all system parameters
• Precise current control (<5% ripple variation)
• Intelligent Voltage control
• No need to bin LEDs for Vf
• Auto detect and compensates for Vf drop in cable
• Auto compensate for driver-fixture distances
• Optical Feedback
• Auto White CCT variation
• Multi-colour LED to White CCT control
• Thermal Management
• Intelligent PSU temperature management
• LED fixture thermal management
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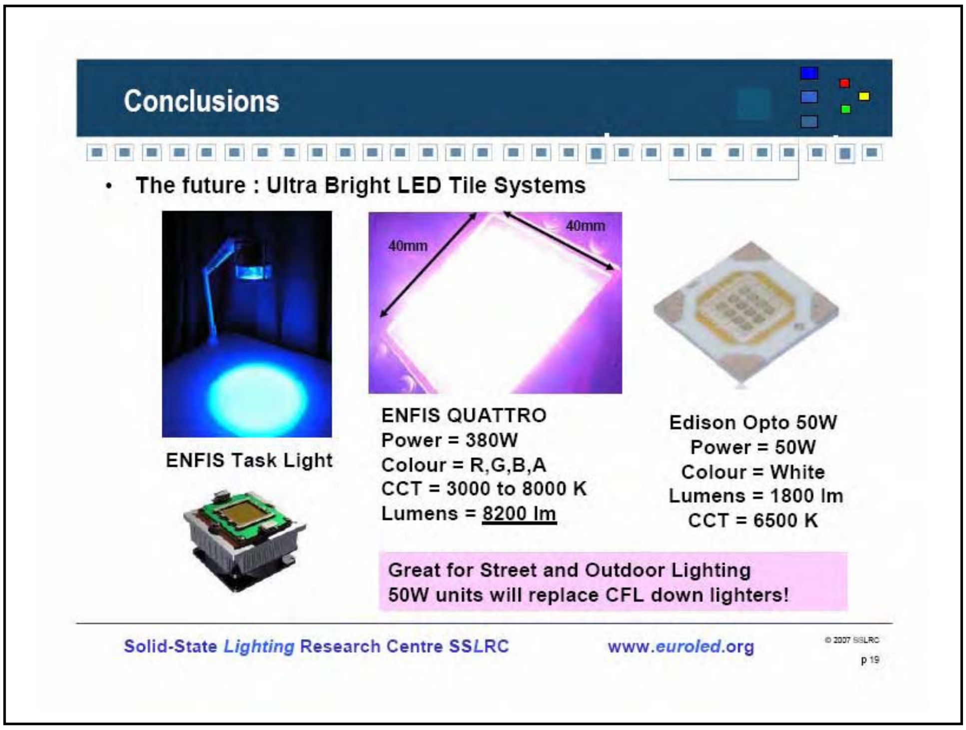
Conclusions
• The future : Ultra Bright LED Tile Systems
40mm
40mm
ENFIS Task Light
ENFIS QUATTRO
Power = 380W
Colour = R,G,B,A
CCT = 3000 to 8000 K
Lumens = 8200 lm
Edison Opto 50W
Power = 50W
Colour = White
Lumens = 1800 lm
CCT = 6500 K
Great for Street and Outdoor Lighting
50W units will replace CFL down lighters!
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Conclusions

- 2006 was a vital year in the development of LEDs
- High Power White LEDs have reached 100 lm/W
- The lumen cost of LEDs has dropped by ~30% during the year
- Intelligent and simple-to-use LED drivers are now available
- Many solutions for overcoming the LED challenges are being created
- The LED and SSL market is growing significantly
- Ultra Bright LED Tiles are being developed to provide > 6000 lumens output in an LED of 40mm x 40mm
- More support for companies to design and measure LED fixtures – eg; SSLRC
- By 2020 the SSL market will be predicted to be worth $155bn!

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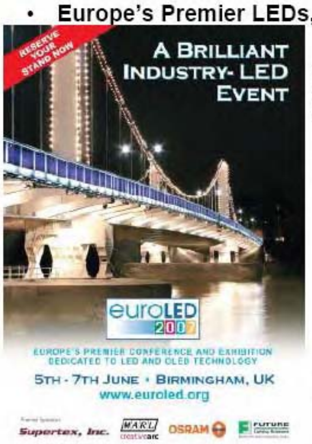
And Finally.....

- Europe's Premier LEDs, OLED and SSL conference and Exhibition



Day 1: Pre-conference seminars and workshops

o Conference workshops addressing practical challenges in developing LED lighting fixtures, driving LEDs etc

oDiscussing LED standards and recommendations

Day 2: Market Overview and Technologies

Sessions will cover:

- o Latest LED and OLED technologies from global manufacturers
- o Global markets and trends – LED and OLED
- o Thermal management
- o Phosphors and packaging

Day 3: Solid-State Lighting Applications

Sessions will cover LED standards and Safety, Stage and Theatre lighting, Architectural, Retail and Commercial lighting

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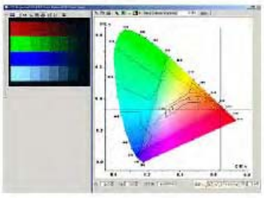
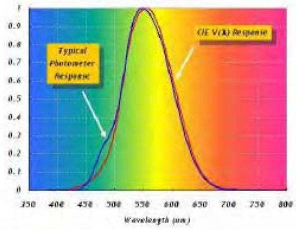
Photometric Training Course for Lighting and LED Design Engineers

A 1-day course course introducing practical light & colour measurement



A foundation in the measurement, analysis and application of the fundamental lighting quantities used on a daily basis by those practicing LED lighting design, and more widely, engineers and technicians engaged in photometry work within industry



Course Outline

1. Introduction to Light Measurement
2. Colourimetry
3. Review of Equipment used for Photometry
4. Practical Laboratory Measurements

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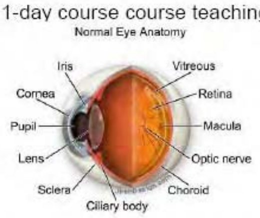
LED Eye Safety Training Course for Lighting and LED Design Engineers, Specifiers and Manufacturers

A 1-day course course teaching how to understand the hazards of high power LEDs



Learn how to develop safe LED-based products compliant with International Standards.

Modern High Power LEDs have the potential to cause serious injury to the eye and a thorough understanding of where the responsibility lies for safe LED product development is paramount.

Course Outline

1. Optical Radiation Hazards
2. LED Beam Properties
3. LED & Laser Safety Analysis (IEC 60825-1)
4. LED & Lamp Safety Analysis (CIE 009:2002)
5. LED Arrays & Advanced Concepts

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Thank You for Your Attention
Further Market and Technical Information @
www.euroleds.org/articles
Any Questions?
Dr Geoff Archenhold
Solid-State Lighting Research Centre
Email: geoffa@astonsciencepark.co.uk
Web: www.euroLED.org


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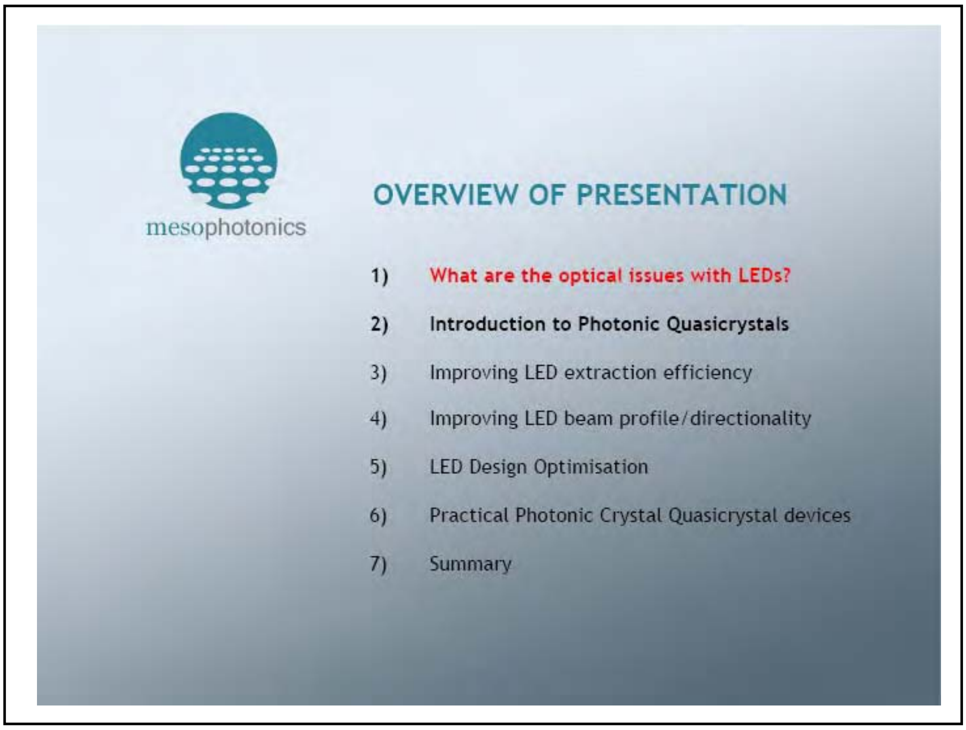
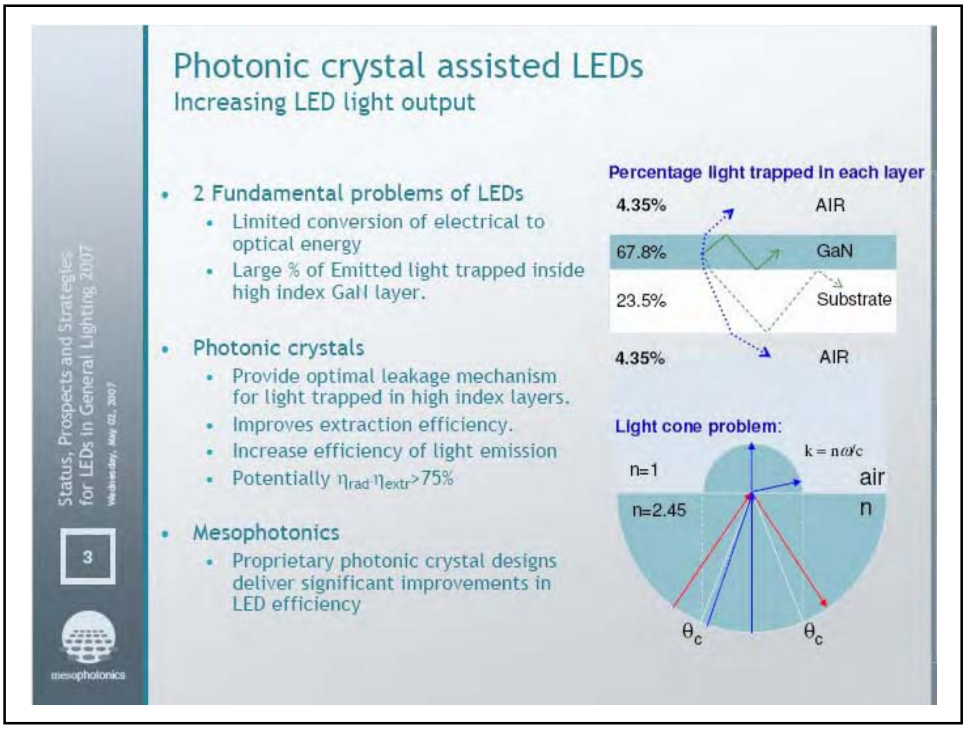
High Brightness Directional Photonic Quasicrystal LEDs.
Majd Zoorob
CTO, Mesophotonics Ltd


mesophotonics
OVERVIEW OF PRESENTATION
1) What are the optical issues with LEDs?
2) Introduction to Photonic Quasicrystals
3) Improving LED extraction efficiency
4) Improving LED beam profile/directionality
5) LED Design Optimisation
6) Practical Photonic Crystal Quasicrystal devices
7) Summary


Photonic crystal assisted LEDs
Increasing LED light output
• 2 Fundamental problems of LEDs
• Limited conversion of electrical to optical energy
• Large % of Emitted light trapped inside high index GaN layer.
• Photonic crystals
• Provide optimal leakage mechanism for light trapped in high index layers.
• Improves extraction efficiency.
• Increase efficiency of light emission
• Potentially $\eta_{rad} \cdot \eta_{extr} > 75\%$
• Mesophotonics
• Proprietary photonic crystal designs deliver significant improvements in LED efficiency
Percentage light trapped in each layer
4.35%
AIR
67.8%
GaN
23.5%
Substrate
4.35%
AIR
Light cone problem:
k = nω/c
n=1
air
n=2.45
n
θ_c
θ_c
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3
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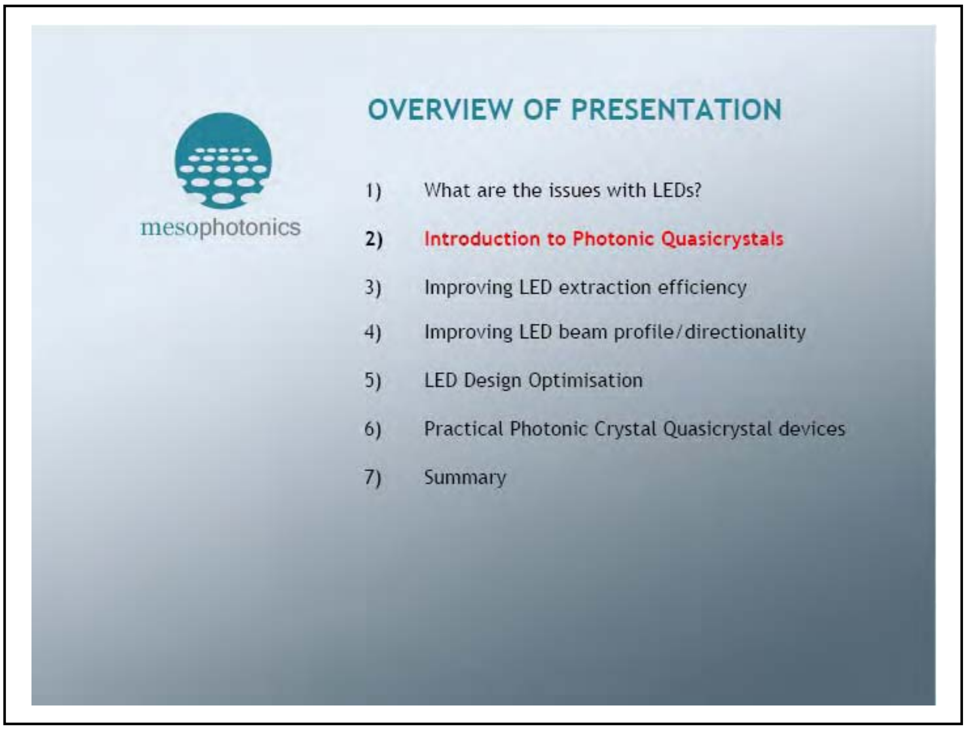
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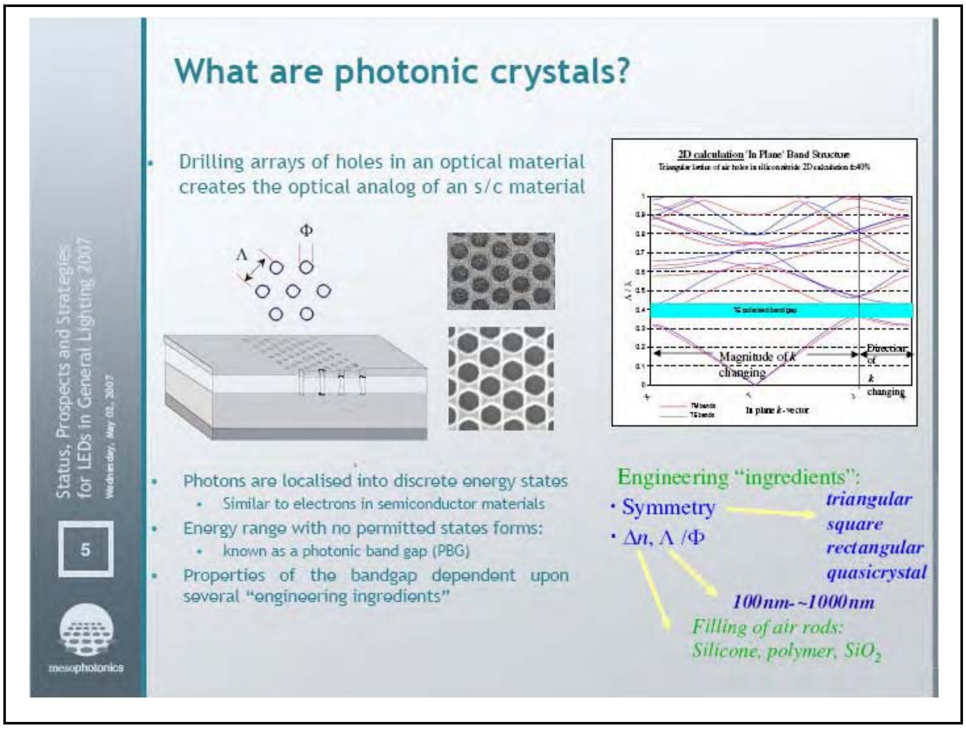
What are photonic crystals?
Drilling arrays of holes in an optical material creates the optical analog of an s/c material
Φ
Λ
2D calculation 'In Plane' Band Structure
Magnitude of k changing
Direction of k changing
In plane k-vector
Photons are localised into discrete energy states
Similar to electrons in semiconductor materials
Energy range with no permitted states forms:
known as a photonic band gap (PBG)
Properties of the bandgap dependent upon several "engineering ingredients"
Engineering "ingredients":
• Symmetry
• Δn, Λ /Φ
triangular
square
rectangular
quasicrystal
100nm-~1000nm
Filling of air rods:
Silicone, polymer, SiO2
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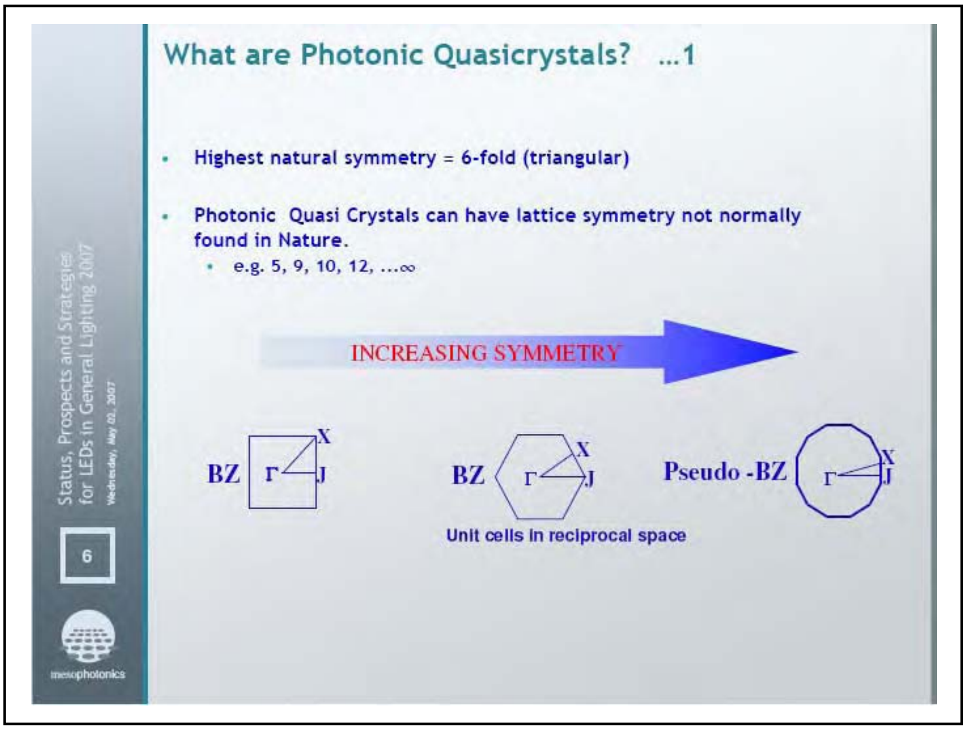
What are Photonic Quasicrystals? ...1
Highest natural symmetry = 6-fold (triangular)
Photonic Quasi Crystals can have lattice symmetry not normally found in Nature.
e.g. 5, 9, 10, 12, ...∞
INCREASING SYMMETRY
BZ
Γ
X
J
BZ
Γ
X
J
Pseudo -BZ
Γ
X
J
Unit cells in reciprocal space
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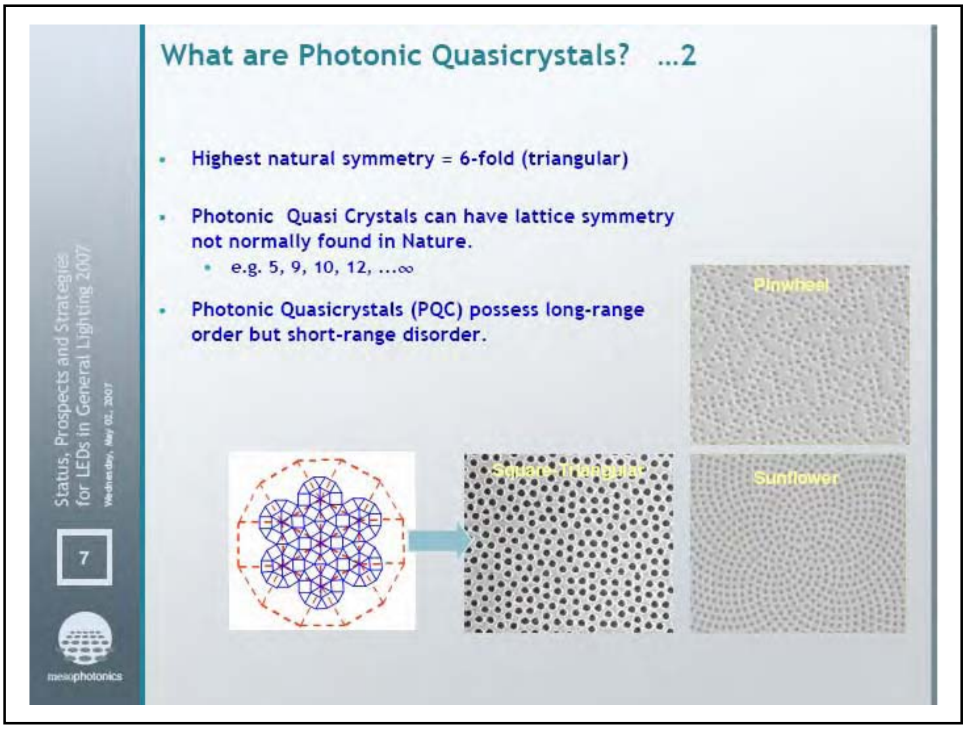
What are Photonic Quasicrystals? ...2
Highest natural symmetry = 6-fold (triangular)
Photonic Quasi Crystals can have lattice symmetry not normally found in Nature.
e.g. 5, 9, 10, 12, ...∞
Photonic Quasicrystals (PQC) possess long-range order but short-range disorder.
Pinwheel
Square-Triangular
Sunflower
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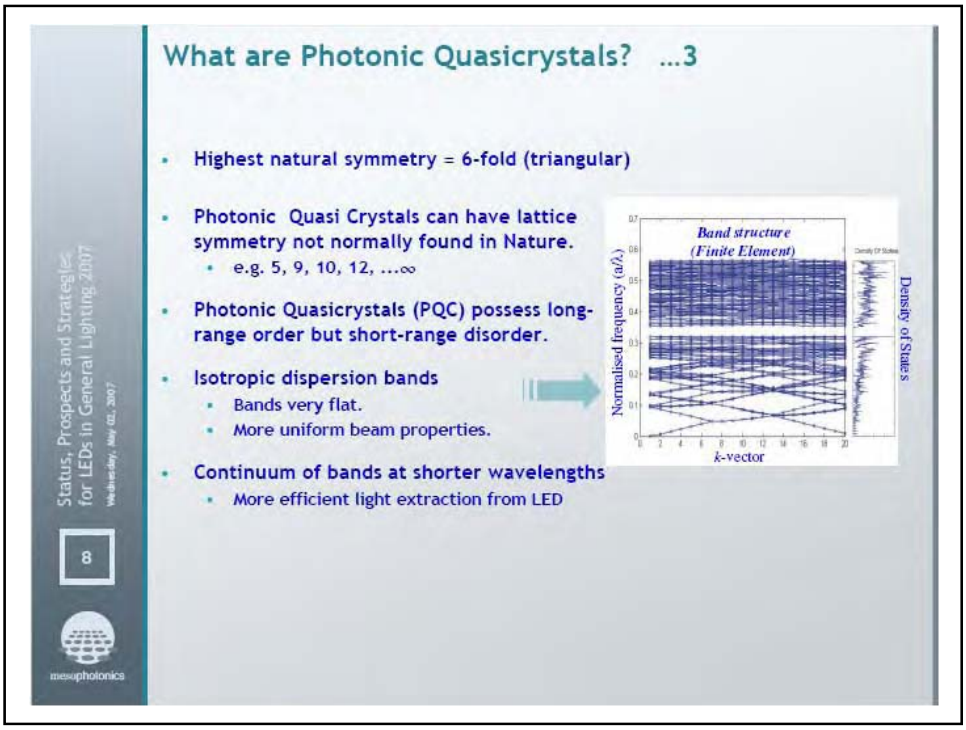
What are Photonic Quasicrystals? ...3
Highest natural symmetry = 6-fold (triangular)
Photonic Quasi Crystals can have lattice symmetry not normally found in Nature.
e.g. 5, 9, 10, 12, ...∞
Photonic Quasicrystals (PQC) possess long-range order but short-range disorder.
Isotropic dispersion bands
Bands very flat.
More uniform beam properties.
Continuum of bands at shorter wavelengths
More efficient light extraction from LED
Band structure (Finite Element)
Normalised frequency (a/λ)
k-vector
Density of States
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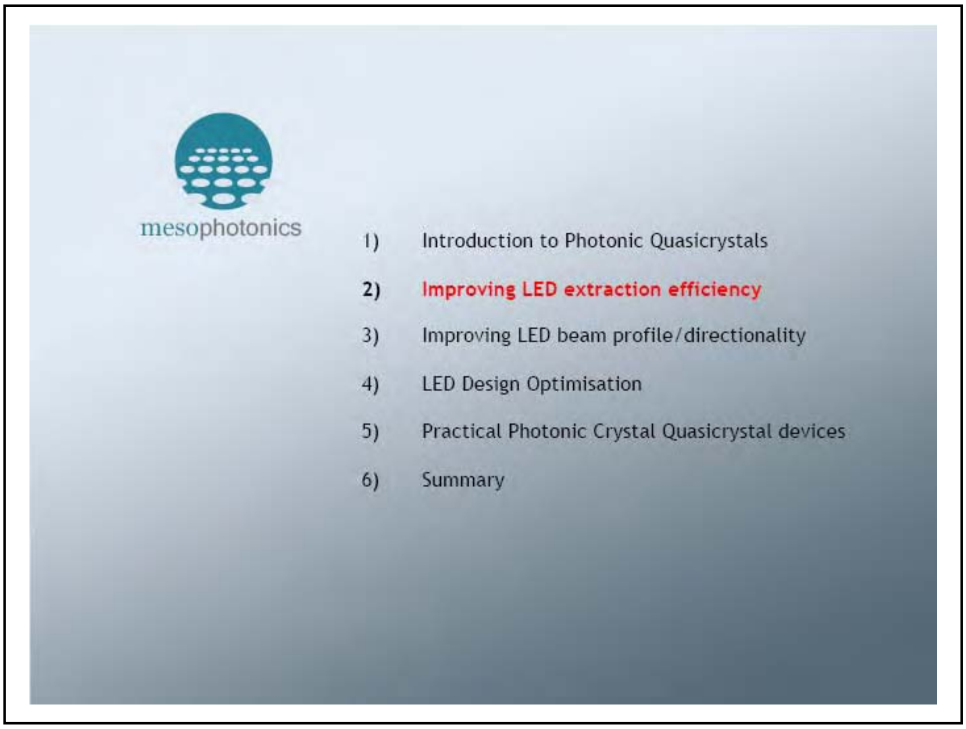
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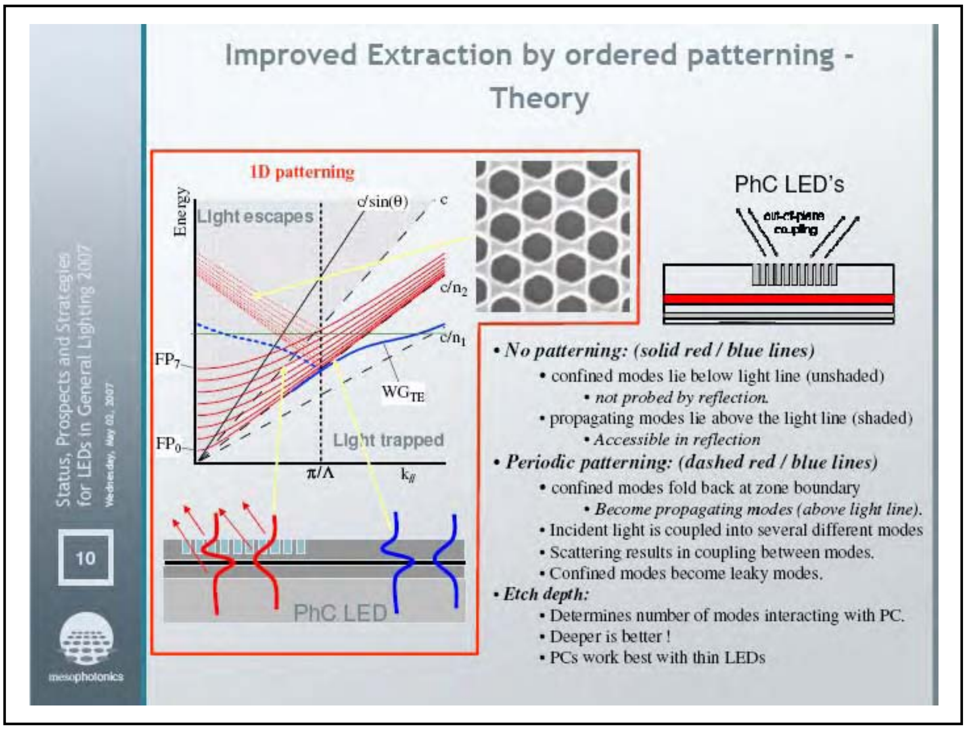
Improved Extraction by ordered patterning - Theory
1D patterning
Energy
Light escapes
c/sin(θ)
c
c/n2
c/n1
FP7
FP0
WGTE
Light trapped
π/Λ
PhC LED
PhC LED's
• No patterning: (solid red / blue lines)
• confined modes lie below light line (unshaded)
• not probed by reflection.
• propagating modes lie above the light line (shaded)
• Accessible in reflection
• Periodic patterning: (dashed red / blue lines)
• confined modes fold back at zone boundary
• Become propagating modes (above light line).
• Incident light is coupled into several different modes
• Scattering results in coupling between modes.
• Confined modes become leaky modes.
• Etch depth:
• Determines number of modes interacting with PC.
• Deeper is better !
• PCs work best with thin LEDs
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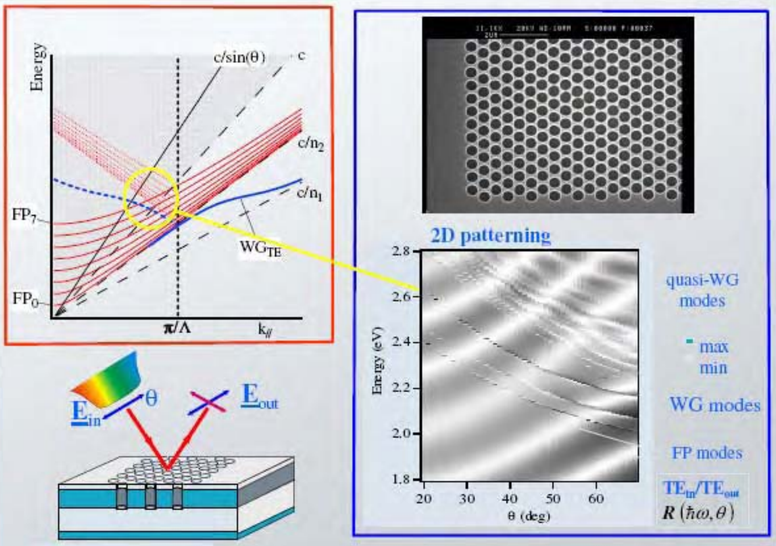
Improved Extraction by ordered patterning - Experiment



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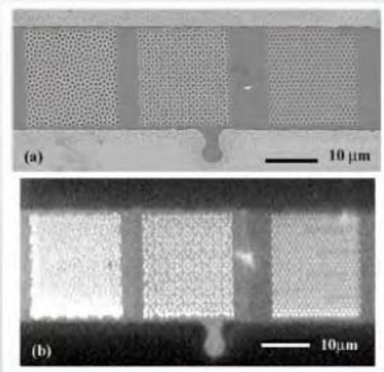
PQC-LEDs in the literature.

- PQC-LEDs recently gaining much attention in literature.
- Zhang et al. (Peking Uni) quote x2 enhancement in extraction over regular PC-LED structures



Zhang et al. (Peking Uni) APL 88, 17103, 2006.

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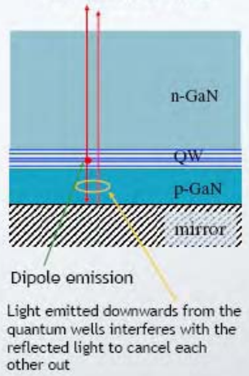
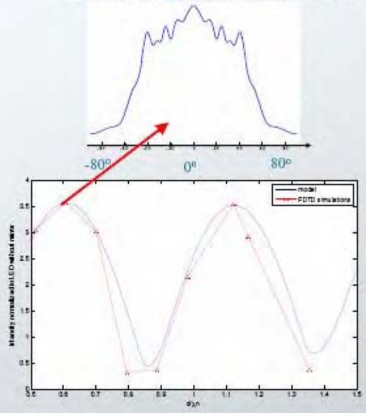
"Optical Cavity" LEDs (No Photonic Crystals)

Vertical Structure



Radiation profile inside GaM



If tuned properly, the micro-cavity with a perfectly reflective mirror can give an enhancement of 1.75 over an LED with a mirror and no micro-cavity effect

(Validation of FDTD model)

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PQCLEDs - How much can be gained?

Extraction Enhancement Summary

	PQC with cavity	Roughness
Mirror	x2	x2
cavity	x1.75 (perfect)	x1.75 (perfect)
PC/roughening	x2.5	x2.5

	Total extraction eff		% light in 30⁰ cone	
	cavity	no cavity	cavity	no cavity
Bare LED	4.4%	4.4%	24.3%	24.3%
mirror	8.7%	8.7%	24.3%	24.3%
cavity + mirror	15.2%	x	23.7%	x
PC + cavity + mirror	**38.1%**	**21.8%**	**41%**	**41%**
Roughness	38.1%	21.8%	24.5%	x
PC+ cavity + mirror + encapsulation*1	**~91.4%**	**x**	**41%**	**41%**

Encapsulation can be designed to work with PCs

Enhancement of light in 30⁰ cone	with cavity
Ratio PQC/roughened	x1.6

*1Encapsulation assumed hemispherical and much larger than LED chip.

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OVERVIEW OF PRESENTATION

1) **What are the issues with LEDs?**
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3) **Improving LED extraction efficiency**
4) Improving LED beam profile/directionality
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6) Practical Photonic Crystal Quasicrystal devices
7) Summary

Benefits of PQC-LEDS

Application specific emission profiles

- Increase LED efficiency for a given application.
- Simple lower cost packaging.
- Reduced P_{out} binning.
- improved thermal management.

Novel design freedom

- Even far-field illumination
  - non Lambertian emission.
- Cone-shape emission
- Bat wing emission
- Change of pattern design can make a given LED epi structure suitable for many diverse applications.

PC-LED

Contrast enhanced Far-field image

PQC-LED

Far-field image

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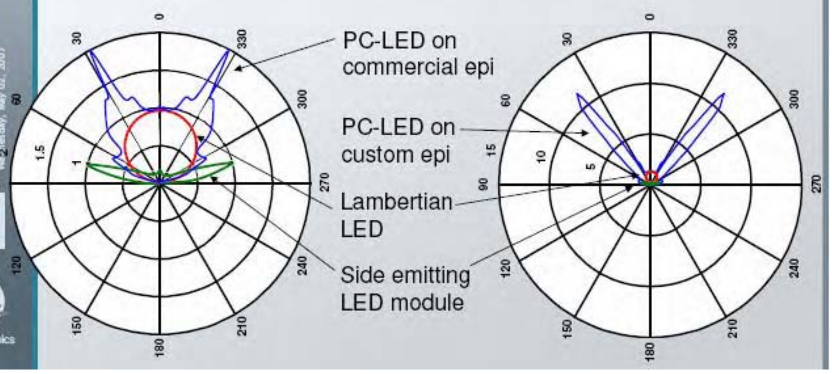
Bat wing PQC-LEDs - for large screen LCD BLU

	Lambertian LED	Unoptimised Current PQC-LED	Thin PQC-LED
Total enhancement	x1.0	x2.0	x4.9
Normalised light in lobes	x1.0	x2.5	x8.9



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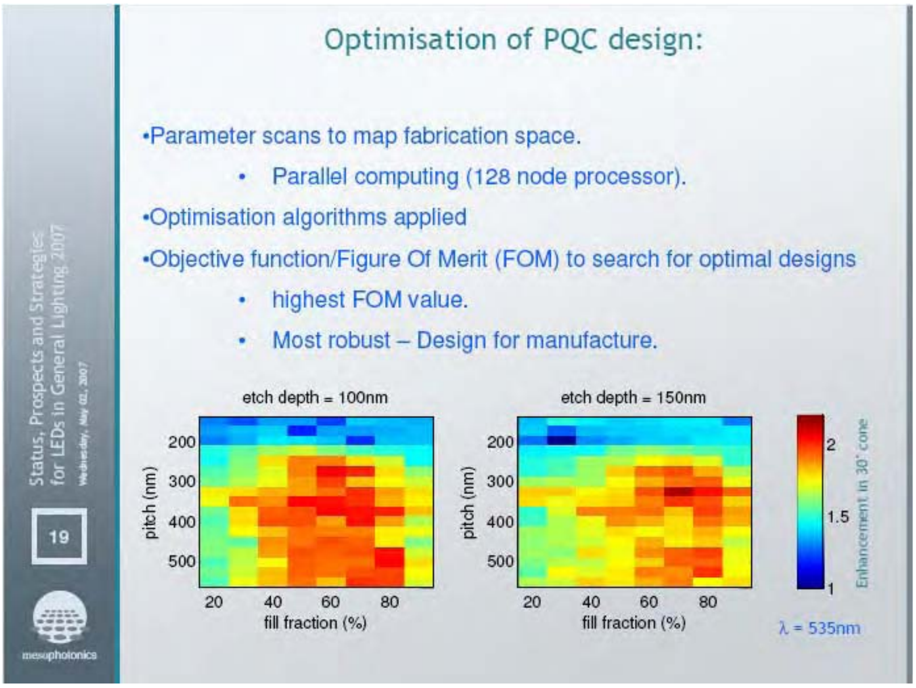
Optimisation of PQC design:
•Parameter scans to map fabrication space.
• Parallel computing (128 node processor).
•Optimisation algorithms applied
•Objective function/Figure Of Merit (FOM) to search for optimal designs
• highest FOM value.
• Most robust – Design for manufacture.
etch depth = 100nm
etch depth = 150nm
pitch (nm)
200
300
400
500
20
40
60
80
fill fraction (%)
Enhancement in 30° cone
2
1.5
1
λ = 535nm
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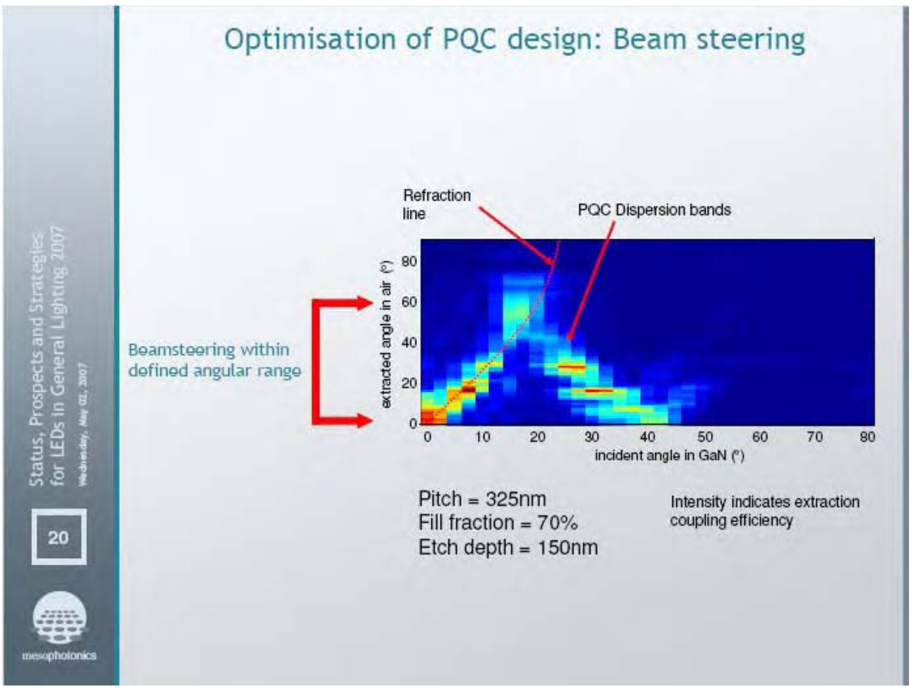
Optimisation of PQC design: Beam steering
Beamsteering within defined angular range
Refraction line
PQC Dispersion bands
extracted angle in air (°)
0
20
40
60
80
0
10
20
30
40
50
60
70
80
incident angle in GaN (°)
Pitch = 325nm
Fill fraction = 70%
Etch depth = 150nm
Intensity indicates extraction coupling efficiency
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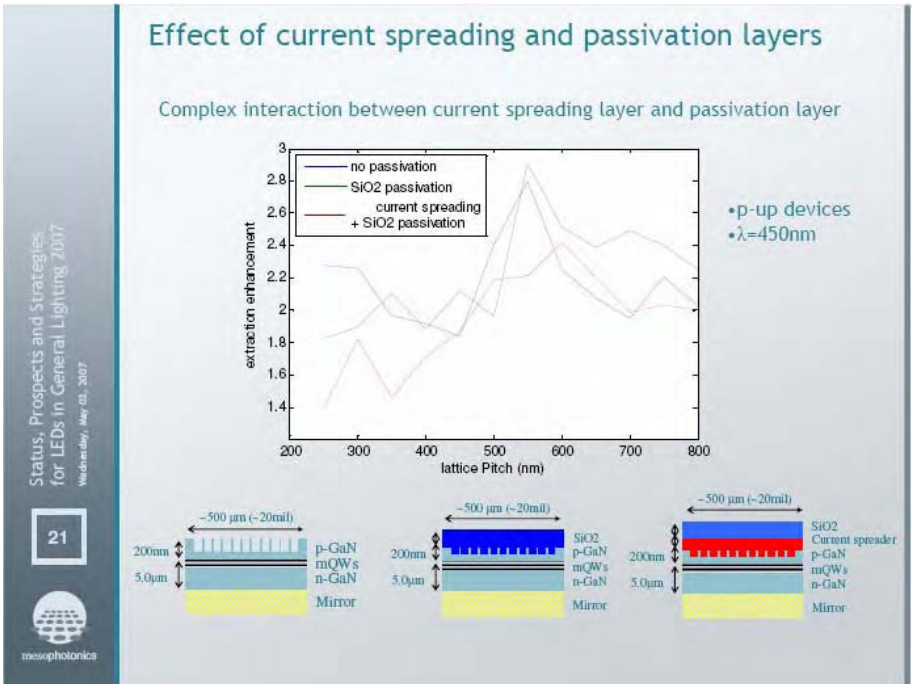
Effect of current spreading and passivation layers
Complex interaction between current spreading layer and passivation layer
no passivation
SiO2 passivation
current spreading + SiO2 passivation
extraction enhancement
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
200
300
400
500
600
700
800
lattice Pitch (nm)
•p-up devices
•λ=450nm
~500 µm (~20mil)
200nm
5.0µm
p-GaN
mQWs
n-GaN
Mirror
SiO2
Current spreader
Status, Prospects and Strategies for LEDs in General Lighting 2007
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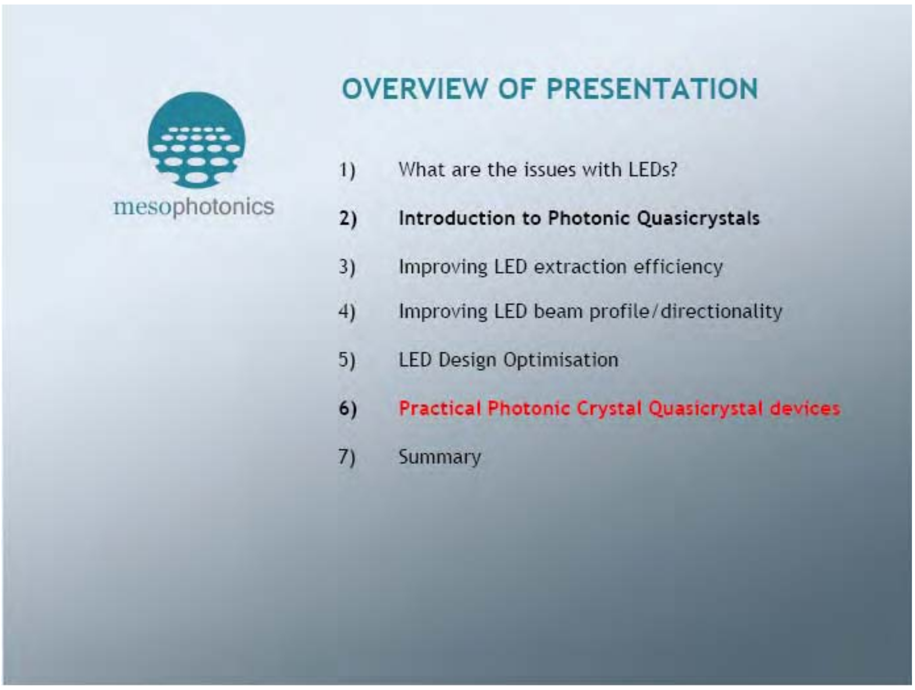
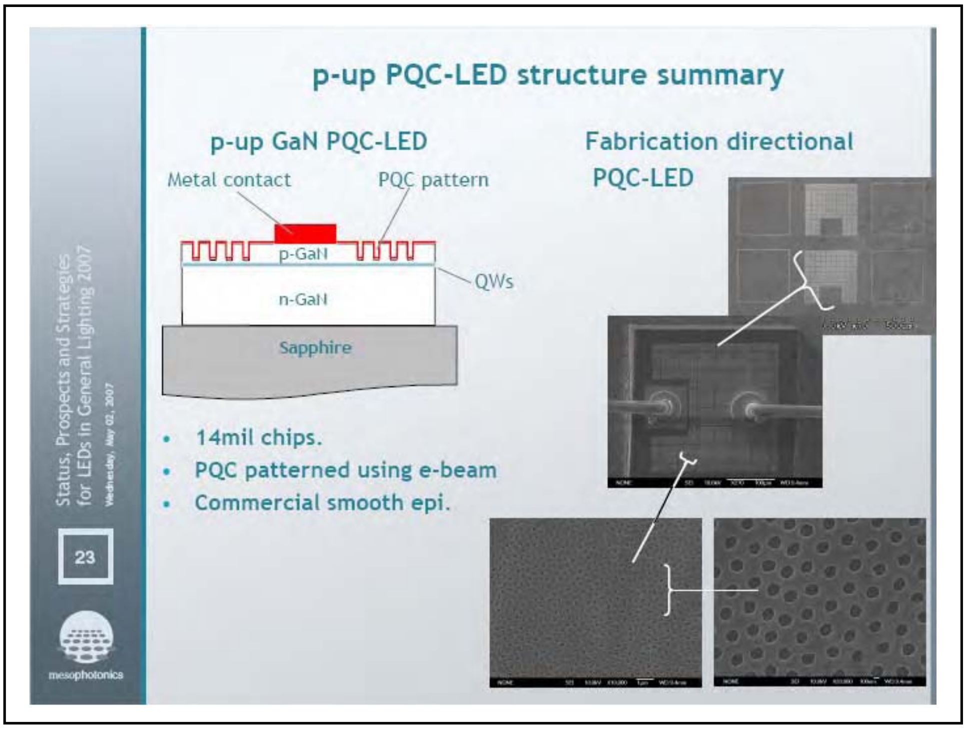

mesophotonics
OVERVIEW OF PRESENTATION
1) What are the issues with LEDs?
2) Introduction to Photonic Quasicrystals
3) Improving LED extraction efficiency
4) Improving LED beam profile/directionality
5) LED Design Optimisation
6) Practical Photonic Crystal Quasicrystal devices
7) Summary


p-up PQC-LED structure summary
p-up GaN PQC-LED
Metal contact
PQC pattern
p-GaN
n-GaN
QWs
Sapphire
• 14mil chips.
• PQC patterned using e-beam
• Commercial smooth epi.
Fabrication directional
PQC-LED
Status, Prospects and Strategies for LEDs in General Lighting 2007
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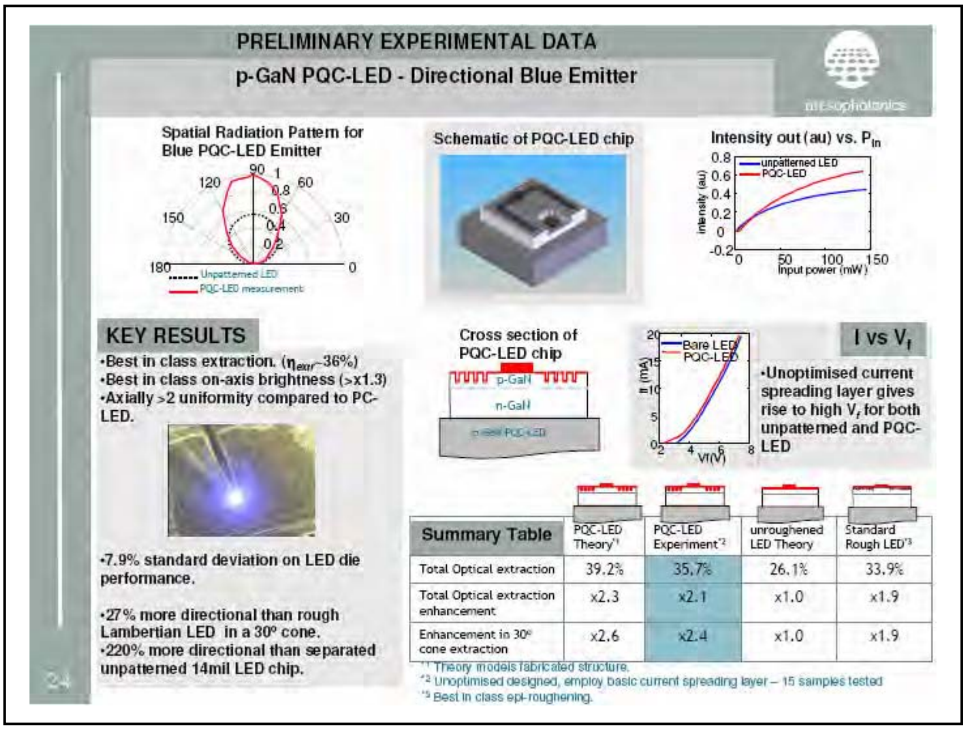
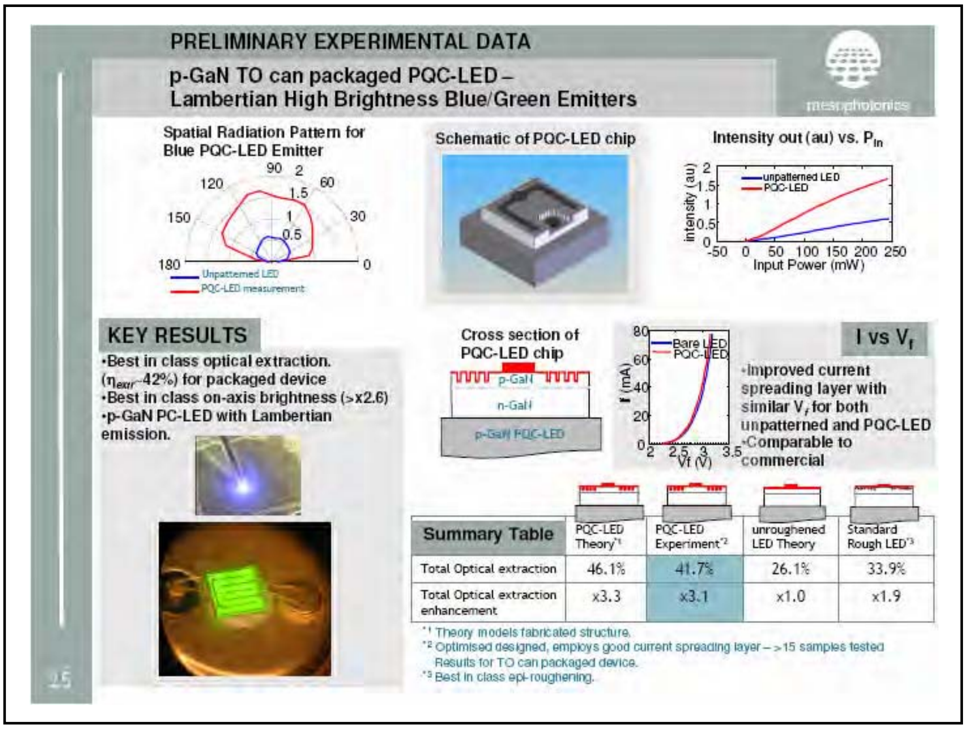
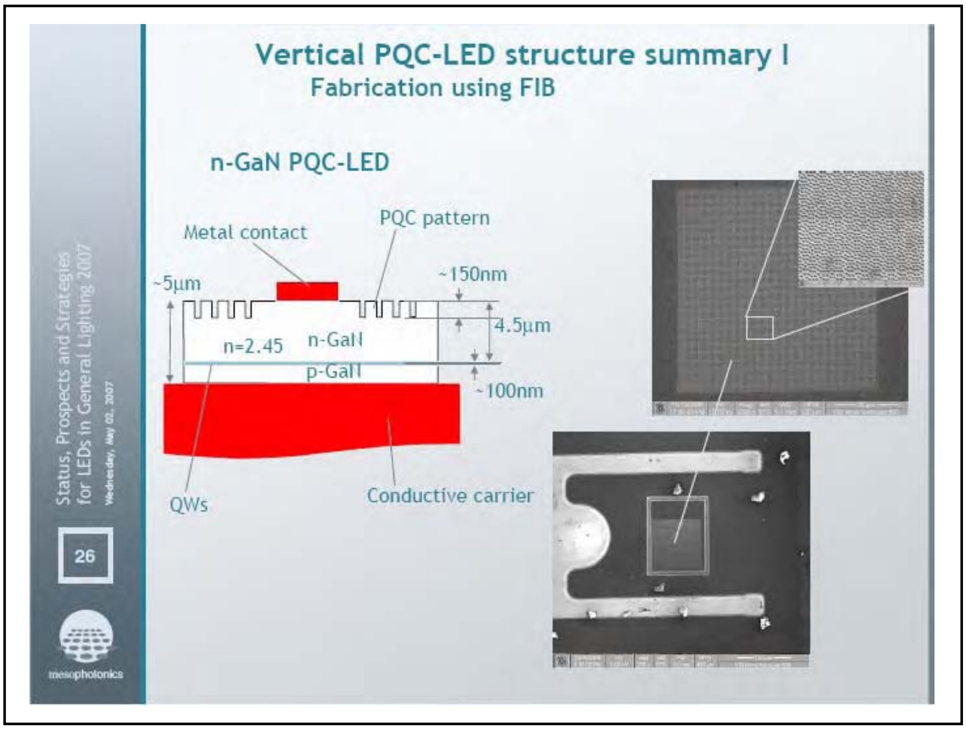

PRELIMINARY EXPERIMENTAL DATA
p-GaN PQC-LED - Directional Blue Emitter
mesophotonics
Spatial Radiation Pattern for Blue PQC-LED Emitter
Unpatterned LED
PQC-LED measurement
Schematic of PQC-LED chip
Intensity out (au) vs. P_{in}
unpatterned LED
PQC-LED
Input power (mW)
KEY RESULTS
•Best in class extraction. (η_{extr}~36%)
•Best in class on-axis brightness (>x1.3)
•Axially >2 uniformity compared to PC-LED.
•7.9% standard deviation on LED die performance.
•27% more directional than rough Lambertian LED in a 30° cone.
•220% more directional than separated unpatterned 14mil LED chip.
Cross section of PQC-LED chip
p-GaN
n-GaN
I vs V_f
Bare LED
PQC-LED
I (mA)
Vf(V)
•Unoptimised current spreading layer gives rise to high V_f for both unpatterned and PQC-LED

Summary Table	PQC-LED Theory*1	PQC-LED Experiment*2	unroughened LED Theory	Standard Rough LED*3
Total Optical extraction	39.2%	35.7%	26.1%	33.9%
Total Optical extraction enhancement	x2.3	x2.1	x1.0	x1.9
Enhancement in 30° cone extraction	x2.6	x2.4	x1.0	x1.9

*1 Theory models fabricated structure.
*2 Unoptimised designed, employ basic current spreading layer – 15 samples tested
*3 Best in class epi-roughening.
24



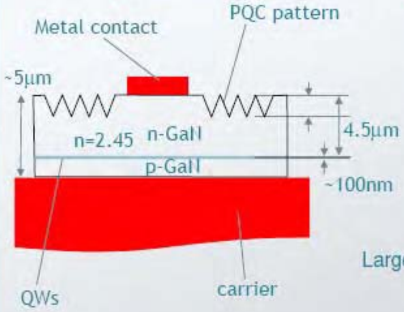
Summary Table	PQC-LED Theory*1	PQC-LED Experiment*2	unroughened LED Theory	Standard Rough LED*3
Total Optical extraction	46.1%	41.7%	26.1%	33.9%
Total Optical extraction enhancement	x3.3	x3.1	x1.0	x1.9



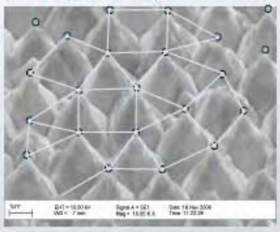
Vertical PQC-LED structure summary II

Fabrication using wet etching

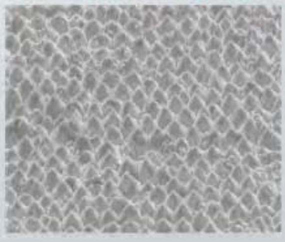
n-GaN pyramidal PQC-LEDs



SEM of PQC square-triangle tiling defined on n-GaN surface of LED. Pyramids pitch ~2.5μm



Large area SEM of PQC tiling - 50μmx50μm



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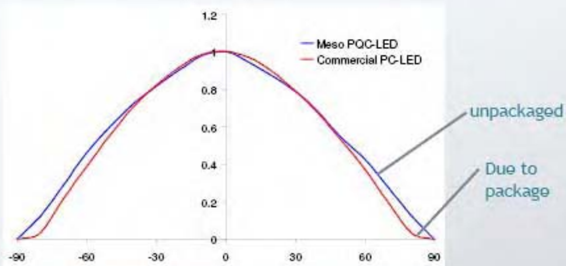
Meso vertical PQC-LED measurements



- First iteration of process.
- Performance similar to commercial PC-LED devices
- Working to improve fabrication process

Collection angle (°)	PQC/lambertian BLUE (% MORE light)
30	21.0

Status, Prospects and Strategies for LEDs in General Lighting 2007
Wednesday, May 02, 2007

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Status, Prospects and Strategies for LEDs in General Lighting 2007
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Summary

Performance

- >90% light extraction from vertical LEDs.
- 40% light in 30° cone.

Technical Benefits:

- Scalable to chip die size.
- Efficient light coupling to application.
- Pattern change modifies application.
- Works on all single colour LEDs (eg R,G and B, not phosphor based.)

End User Benefits:

- Directionality reduces no. of LEDs for application.
- Reproducible roughening - improved binning
  - Potential to double P_{out} yield across wafer.
- Lower cost process to roughening (p-up GaN structures)
- Minimises secondary optics for application.

Corporate Summary

- Investing in volume manufacture with partners
- Showing best-in-class measurements on commercial epi.
- Validating volume production routes with equipment vendors.

Status, Prospects and Strategies for LEDs in General Lighting 2007
Wednesday, May 02, 2007
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Session 2

Chair: Tim Whitaker, LEDs Magazine, UK

FP7 research in Photonics and the Photonics21 Technology Platform

John Magan,
European Commission,
DG INFSO Unit G5

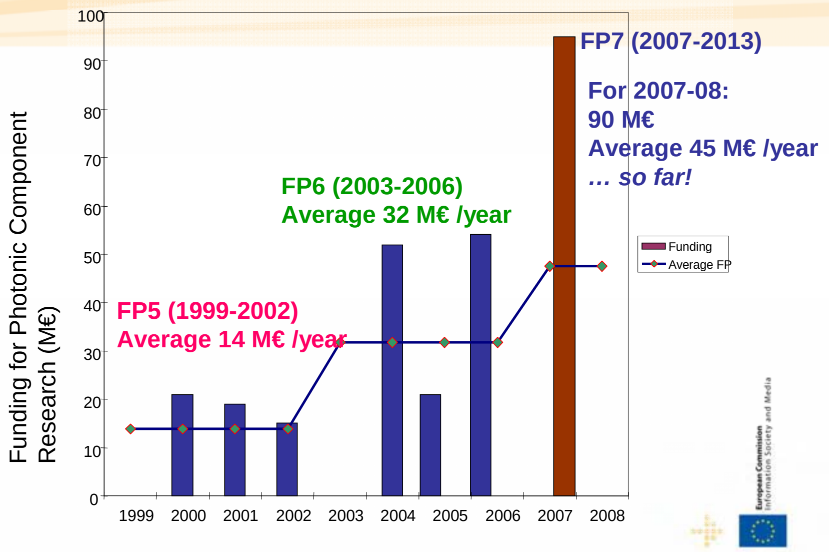
Overview

- Photonics research in ICT
  - The present; ongoing work…
  - The future; FP7
- The Photonics21 Technology Platform

What is the Commission doing for photonics?

- The Commission has increased the overall budget for FP 7.
- Photonics has been given a strong emphasis in FP 7:
  - A 40% budget increase for *Photonic Components:- 90 M€ (2007-08)*
  - A single unit has been created for Photonics
  - Further increase during FP7 foreseen.
- Photonics is visible in many other areas of the FP7 programme.

Photonics funding in the Framework Programmes – *quantum leaps and bounds!*

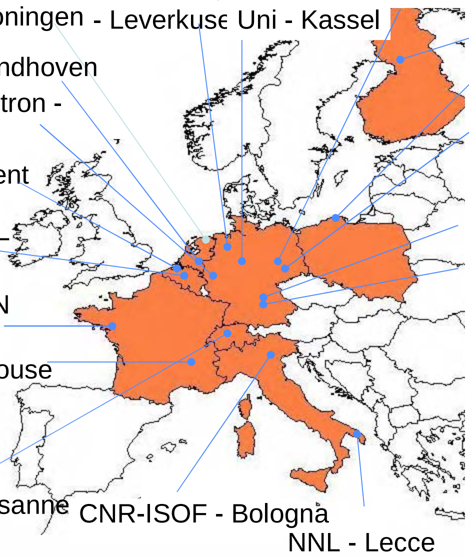


The OLLA project

High Brightness
Organic Light Emitting Diodes
for
ICT & Lighting Applications

www.olla-project.org

OLLA – partners

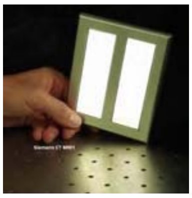


OLLA Consortium:

24 Partners:

- 10 Industries
- 7 Institutes
- 7 Universities

Final target: OLLA light-tile



Brightness: 1000 cd/m²
Efficiency: 50 lm/W
Lifetime: 10.000 h
Color Rendering Index: >70
Size: 30cm x 30cm
Colour: white

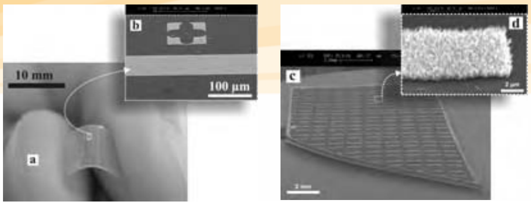
All spec's within the same demonstrator!

Prototype proves OLEDs for general illumination

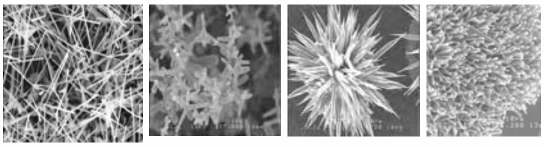
Nanophotonic and Nanoelectronic Devices from Oxide Semiconductors (NANDOS)

- Grow self-organised ZnO nanostructures on various substrates
- Optimise the control of self-organisation
- Demonstrate ZnO nanodevices: UV and white light nano-LEDs, ZnO nanolasers at room temperature
- Optimise fabrication processes

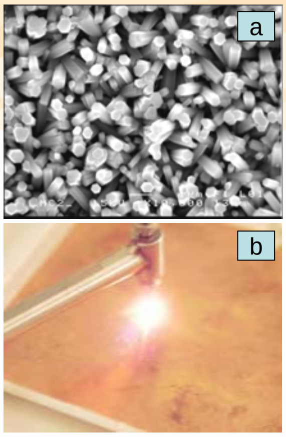
NANDOS



Patterned arrays of ZnO nanopillars generated via postgrowth lithography / wet chemical etching:
(a) photograph of PEN foil;(b) SEM picture of PEN foil enlarged of (a); c) SEM picture of silicon (100); (d) SEM enlarged of (c)



Various ZnO nanostructures grown on Si substrates at different conditions by vapor-liquid-solid .



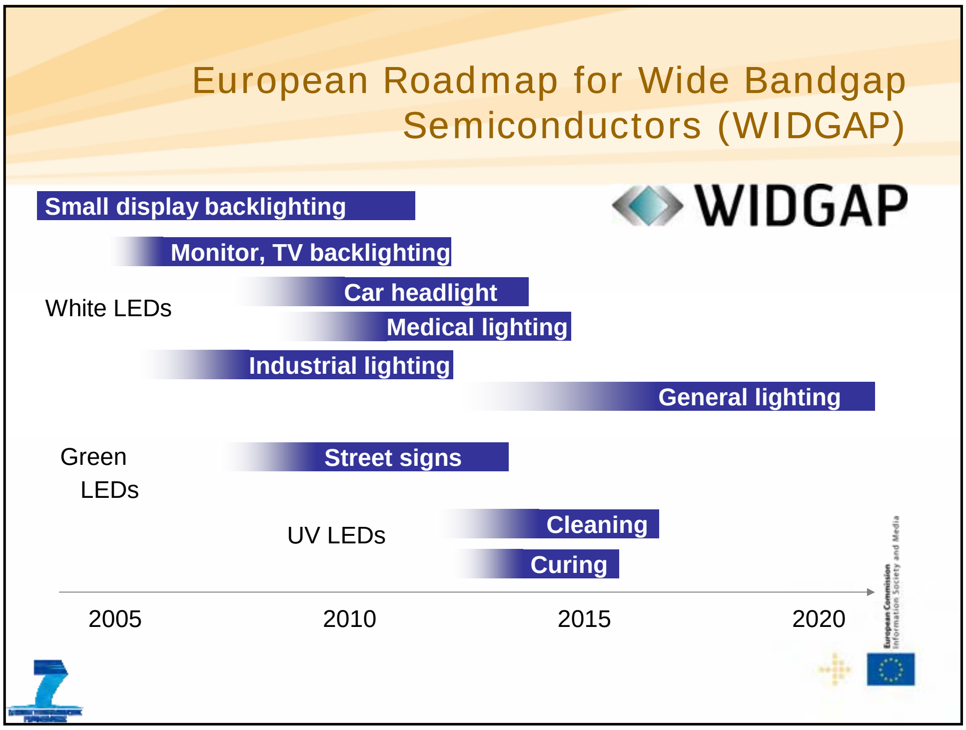
(a) SEM image of ZnO nanorods grown at low temperature on ITO
(b) white light emission from ZnO nanrod LED made from (a)

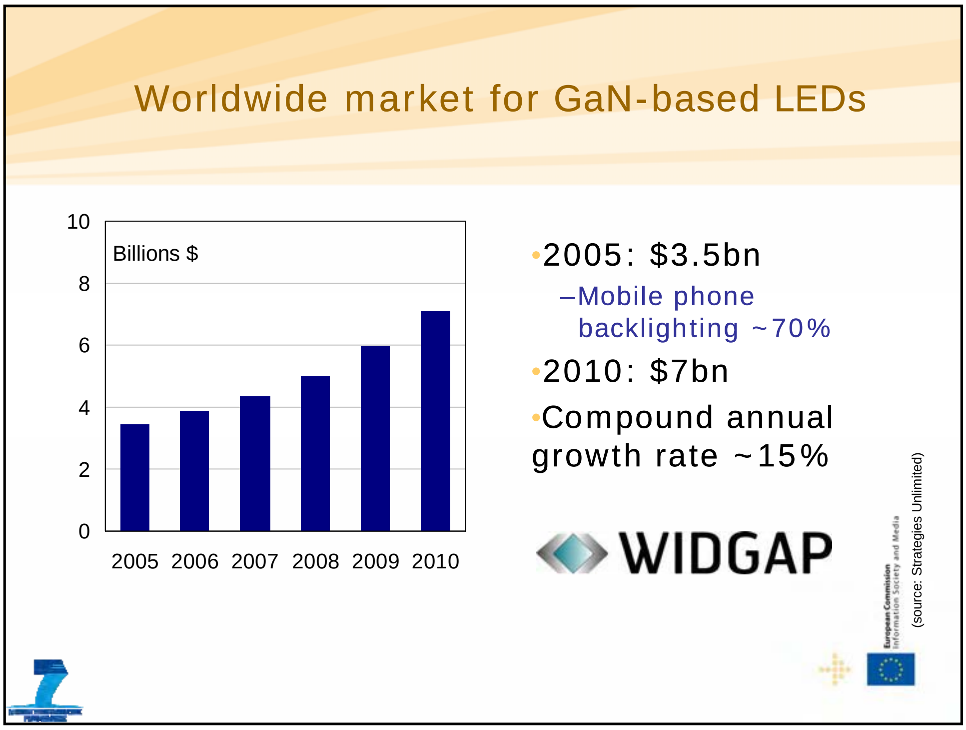
Merging Optics and Nanotechnologies (MONA)

- Does roadmapping for nanophotonics in Europe so as to leverage synergies in photonics and nanotechnologies, and contribute to the coordination of research
- Specific roadmap segments being prepared for lighting:
  - Semiconductor quantum dots and wires in III-V for lighting applications
  - II-VI nano wires for lighting (e.g. ZnO)
  - Plasmonics/metallic nanostructures for lighting applications
  - Photonic crystals & high index nanostructures in III-V for lighting applications

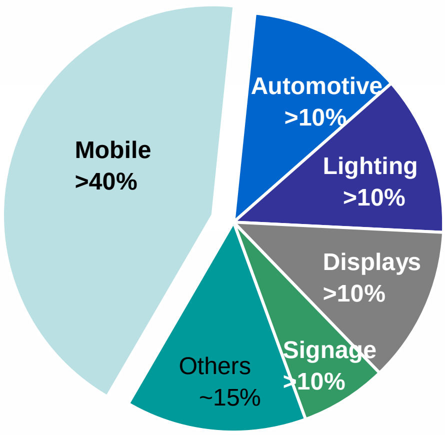
www.ist-mona.org

European Commission
Information Society and Media


European Roadmap for Wide Bandgap Semiconductors (WIDGAP)
WIDGAP
White LEDs
Small display backlighting
Monitor, TV backlighting
Car headlight
Medical lighting
Industrial lighting
General lighting
Green LEDs
Street signs
UV LEDs
Cleaning
Curing
2005
2010
2015
2020


Worldwide market for GaN-based LEDs
Billions $
10
8
6
4
2
0
2005 2006 2007 2008 2009 2010
•2005: $3.5bn
–Mobile phone backlighting ~70%
•2010: $7bn
•Compound annual growth rate ~15%
WIDGAP
(source: Strategies Unlimited)

Distribution of LED market value by applications in 2010



Mobile applications (phones but also DSC, consoles, MP3 players) remain the main market

- Displays, also keyboard, flash

Display backlighting for large LCD (12“ and beyond) is emerging and poised to grow very fast

- emerging market in projectors

Compared to other applications, solid state lighting exploits only a fraction of ist potential in the short term

Key technology issues

- White LEDs
- Increase efficiency (target: 120 lm/W)
- Develop new packaging for thermal dissipation
- Improve phosphors (better efficiency)
  - Efficiency
  - Hue
- Insure consistency of colour across production
- Reduce cost

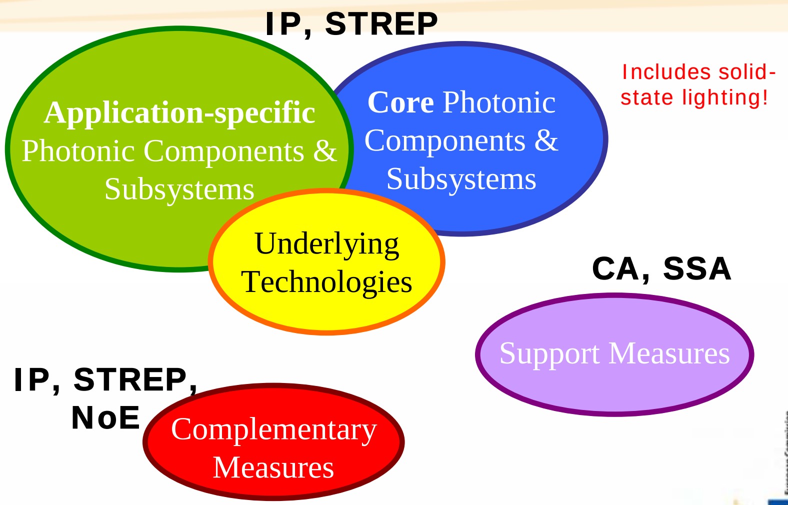
- Laser diodes
- Improve reliability
- Increase output power (green laser)
- Reduce costs

WIDGAP

Photonics in ICT: what's open for funding in 2007

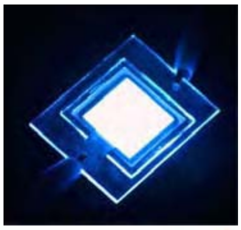
- Photonic Components & Subsystems Objective ICT-2007.3.5 in ICT Call 2 (FP7-ICT-2007-2)
- Call 2 to be published 15 May 2007 (tbc)
- Call closure 9 October 2007 (tbc)
- Indicative budget = 90 M€

Photonics in ICT R&D Objectives:
Overview in 2007-2008 Workprogramme



Photonics 2007-2008 topics - 1

- **Core photonic components and subsystems for multiple application fields**
  - High performance lasers
  - High brightness, power efficient solid state light sources (also for general lighting)
  - High performance optical fibres
  - High performance image sensors
  - Sensors exploiting innovative sensing principles



Photonics 2007-2008 topics - 2

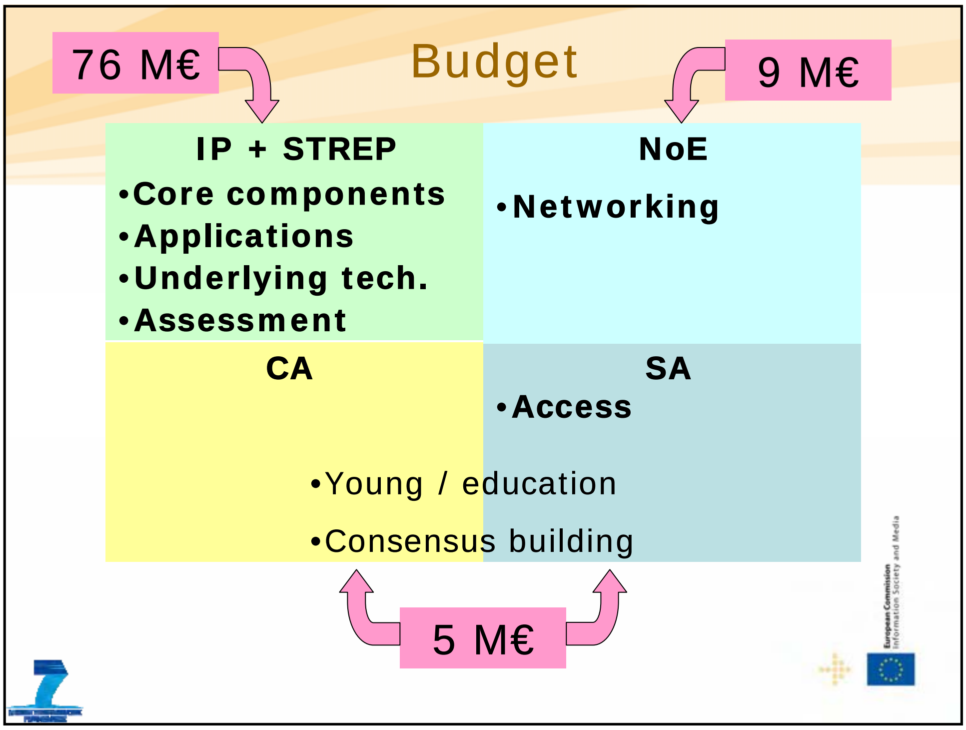
- **Components and subsystems for specific strategic applications**
  - for truly cost effective broadband core networks at 40 Gb/s and beyond
  - for scalable, future-proof and economic broadband access and LAN
  - for minimally invasive medical diagnosis and prevention
  - for sensing for environment, well-being, safety and security

Photonics 2007-2008 topics - 3

- **Underlying technologies:**
  - Integration technologies: holistic approaches for reducing size and cost and improving performance, manufacturability, testability, increasing functional integration and advancing photonics/electronic convergence.
  - Design: methodologies and tools (holistic and widely applicable approaches)- including modelling, simulation, charaterisation and testing

Photonics 2007-2008 topics - 4

- **Complementary and support measures:**
  - Joint assessment by users of prototype components, subsystems and equipment
  - Networking, integration and structuring of advanced photonics R&D capacities and activities
  - Access to centers of expertise and foundries
  - Raising the interest of young people in photonics and stimulating national schemes for graduate education
  - Supporting the development of R&D strategies through, consensus building, coordination with Member States and international cooperation)



Areas supporting Photonics in FP7

- **ICT – Photonics** (Thierry Van der Pyl)
- ICT – Future Networks (Rainer Zimmermann)
- NMP - Materials (Anna Roig)
- NMP - Nanosciences (Heico Frima)
- NMP -New Production (Jyrki Suominen)
- ICT - Organic and large-area electronics and display systems (Marc Boukerche)
- Research for the benefit of SMEs – opportunities for Photonics (Joerg Niehoff)
- FET - Photonics in Future and Emerging Technologies (Wolfgang Boch)

Photonics21 technology platform

Photonics 21

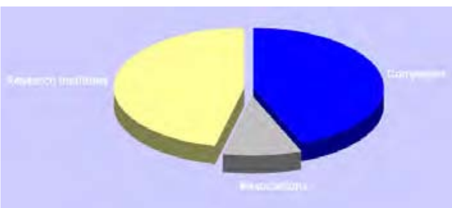
(Photonics for the 21st Century)

- Set up by a broad representation of the Photonics community in Europe
- Facilitate better coordination between
  - industrial actors
  - academic actors
  - European research programmes
  - National research programmes
- Create a Strategic Research Agenda
- An important input to the EU Research Programme

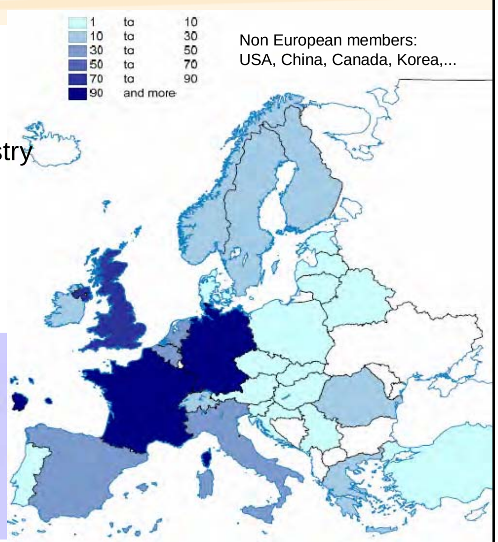
PHOTONICS21

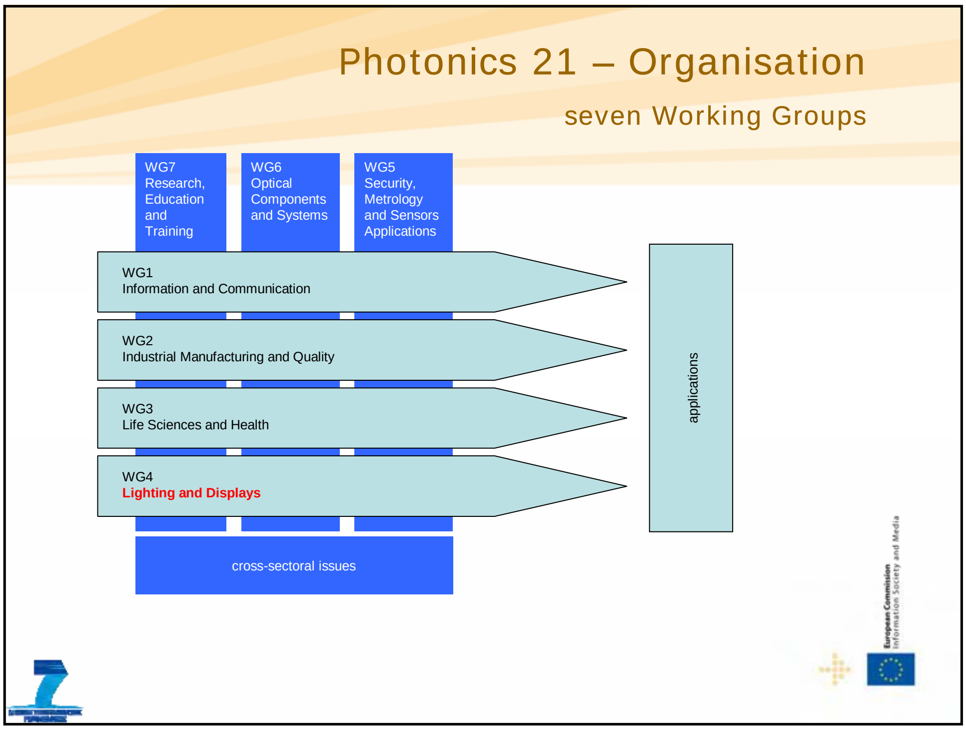
Photonics21 members

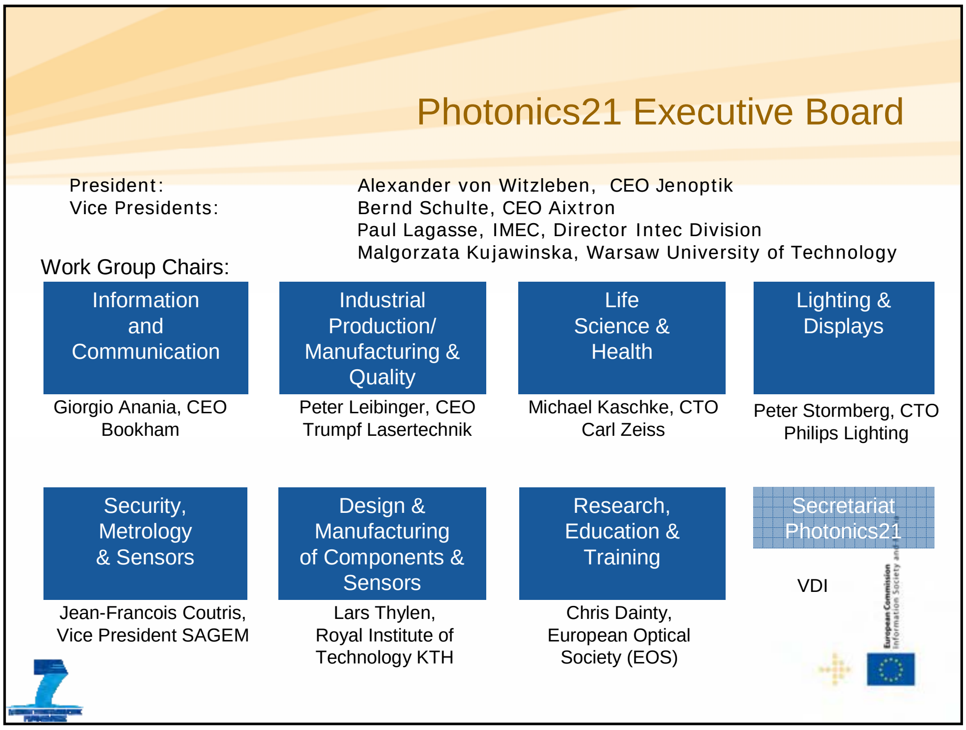
- > 700 members from 37 countries
- 90% members located in EU-25
- Ratio between members from industry and science well-balanced
- Majority of industrial members represent SMEs



Non European members: USA, China, Canada, Korea,...




Photonics 21 – Organisation
seven Working Groups
WG7 Research, Education and Training
WG6 Optical Components and Systems
WG5 Security, Metrology and Sensors Applications
WG1 Information and Communication
WG2 Industrial Manufacturing and Quality
WG3 Life Sciences and Health
WG4 Lighting and Displays
cross-sectoral issues
applications


Photonics21 Executive Board
President: Alexander von Witzleben, CEO Jenoptik
Vice Presidents: Bernd Schulte, CEO Aixtron
Paul Lagasse, IMEC, Director Intec Division
Malgorzata Kujawinska, Warsaw University of Technology
Work Group Chairs:
Information and Communication
Giorgio Anania, CEO Bookham
Industrial Production/ Manufacturing & Quality
Peter Leibinger, CEO Trumpf Lasertechnik
Life Science & Health
Michael Kaschke, CTO Carl Zeiss
Lighting & Displays
Peter Stormberg, CTO Philips Lighting
Security, Metrology & Sensors
Jean-Francois Coutris, Vice President SAGEM
Design & Manufacturing of Components & Sensors
Lars Thylen, Royal Institute of Technology KTH
Research, Education & Training
Chris Dainty, European Optical Society (EOS)
Secretariat Photonics21
VDI

Achievements

- Photonics 21 has created the critical mass which is needed to give a push to photonics in Europe, and has successfully articulated this argument at a political level.
- First version of the Strategic Research Agenda was delivered to Commissioner Reding at Photonics Europe in April 2006.
- This document represents a consolidated input to FP7 from the Photonics community.
- The Strategic Research Agenda should be updated at least every two years.

European Commission
Information Society and Media

Where to find more information

Photonics Unit
Web: http://cordis.europa.eu/fp7/ict/photonics/home_en.html
e-mail: INFSO-PHOTONICS@ec.europa.eu

Photonics21:
www.photonics21.org

Inventory of European Optics and Photonics Research and Industry:
www.opera2015.org

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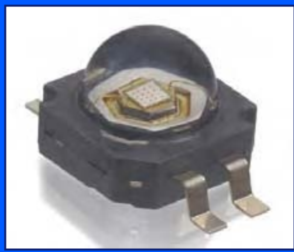

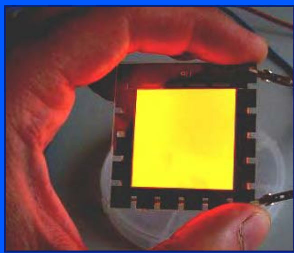

Recent Advances in LED and OLED R&D and their Impact on Energy Saving

Wolfgang O. Budde, Solid State Lighting
Philips Research Europe, Aachen

May 2007

PHILIPS

Lighting accounts for 19% of all Electrical Energy Use World-wide

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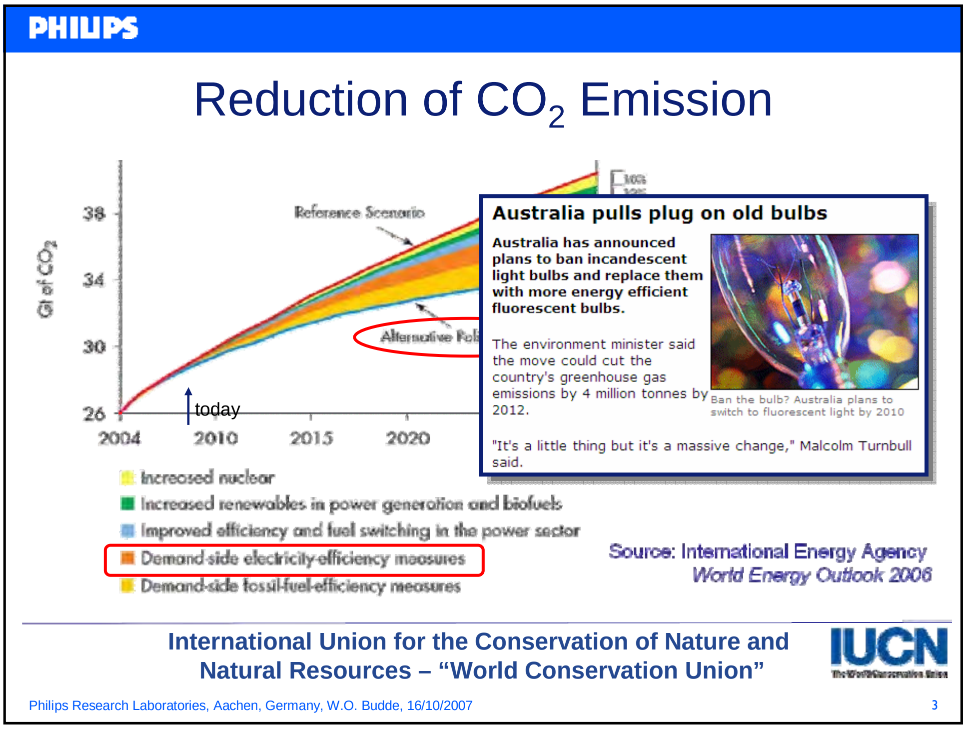
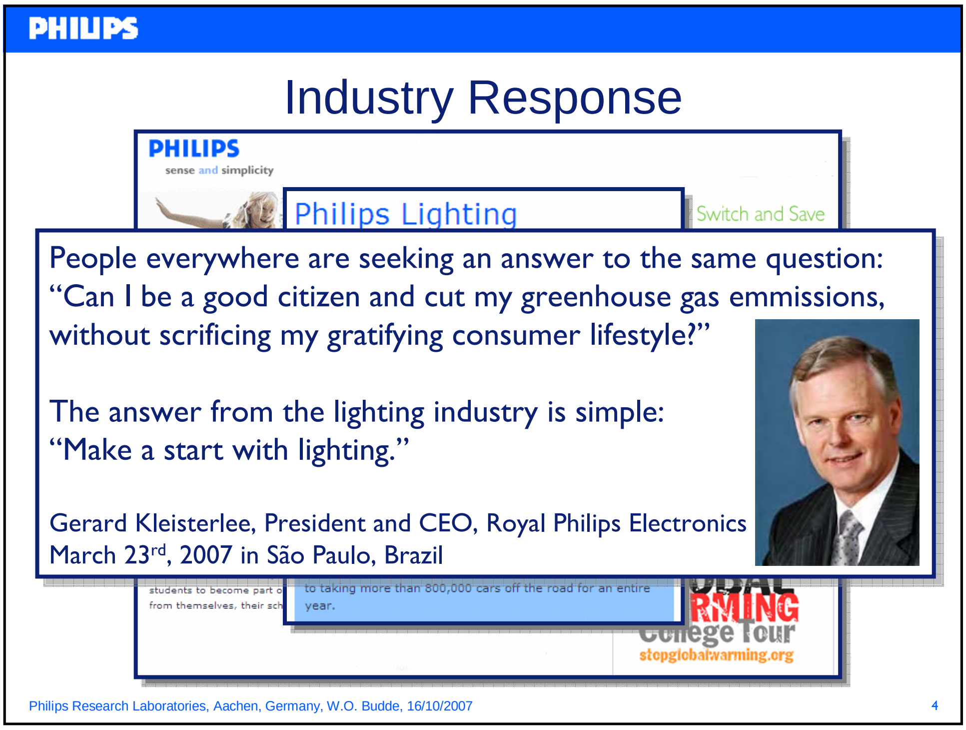

PHILIPS
Reduction of CO2 Emission
38
34
30
26
Gt of CO2
2004
2010
2015
2020
today
Reference Scenario
Alternative Poli
Increased nuclear
Increased renewables in power generation and biofuels
Improved efficiency and fuel switching in the power sector
Demand-side electricity-efficiency measures
Demand-side fossil-fuel-efficiency measures
Australia pulls plug on old bulbs
Australia has announced plans to ban incandescent light bulbs and replace them with more energy efficient fluorescent bulbs.
The environment minister said the move could cut the country's greenhouse gas emissions by 4 million tonnes by 2012.
Ban the bulb? Australia plans to switch to fluorescent light by 2010
"It's a little thing but it's a massive change," Malcolm Turnbull said.
Source: International Energy Agency
World Energy Outlook 2006
International Union for the Conservation of Nature and Natural Resources – "World Conservation Union"
IUCN
Philips Research Laboratories, Aachen, Germany, W.O. Budde, 16/10/2007
3


PHILIPS
Industry Response
PHILIPS
sense and simplicity
Philips Lighting
Switch and Save
People everywhere are seeking an answer to the same question:
"Can I be a good citizen and cut my greenhouse gas emmissions, without scrificing my gratifying consumer lifestyle?"
The answer from the lighting industry is simple:
"Make a start with lighting."
Gerard Kleisterlee, President and CEO, Royal Philips Electronics
March 23rd, 2007 in São Paulo, Brazil
to taking more than 800,000 cars off the road for an entire year.
RMING
College Tour
stopglobalwarming.org
Philips Research Laboratories, Aachen, Germany, W.O. Budde, 16/10/2007
4

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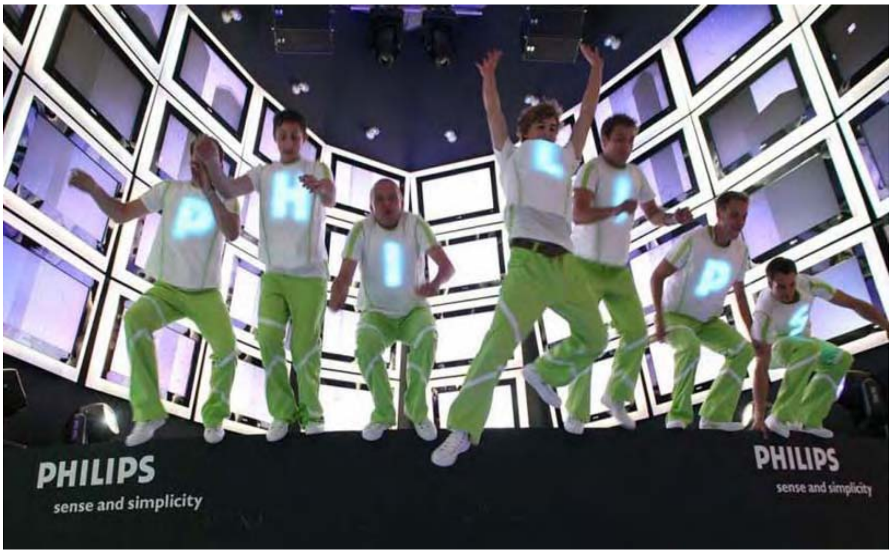
New Functionality vs. Energy Conservation



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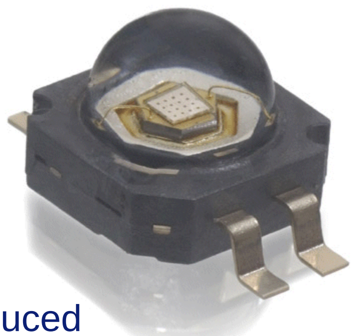
Advances in LED and OLED R&D

- Philips Lumileds sets the World Record in lm/W performance for High Power LEDs
  - 115 lm/W @ 350mA
    136 lm, CCT 4700 K
  - 60 lm/W @ 2000mA
    502 lm, CCT 5000 K
    - ~ 50 W incandescent at 1/6th of electrical power
- Efficacy losses at high drive current (“droop”) reduced
  - Compact, high-intensity light sources enabled



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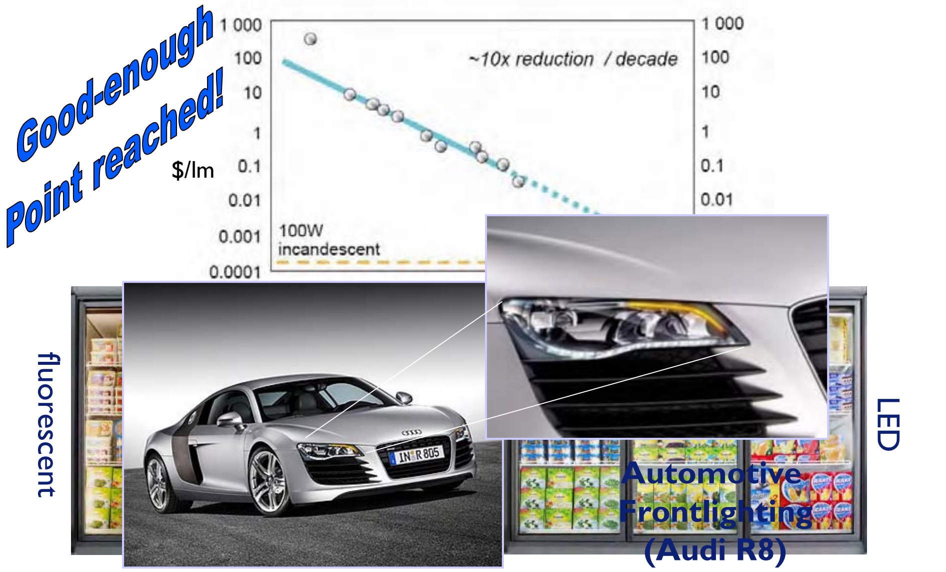
PHILIPS

Volume and Efficacy drive Costs down



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State-of-the-Art in White OLEDs

Konica - Minolta[1]
- 64 lm/W at 1.000cd/m², small size
- 10.000h lifetime (50%), with opt. enhancement

Yamagata University, Prof. Kido [2]
- 48lm/W at 1.000cd/m²
- Lifetime not disclosed, no opt. enhancement

UDC [3]
- 24lm/W at 500cd/m²
- Lifetime not disclosed, with optical enhancement

Philips/Novaled [1]
- 32lm/W at 1000cd/m²
- >20.000h lifetime (50%), with optical enhancement

OLLA
- ITO free OLED device with good performance [4]
- *MS2: 25 lm/W on large size substrates*

1: Company press release
2: Kido et. al., MRS spring meeting San Francisco 2006
3: Y.S. Tsu et al, Nature 2006
4: OLLA project press release April 4, 2006

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OLLA Result: Large Area Homogenous OLEDs

OLLA

IST 2002-4607-OLLA

4 panels of 150x150mm

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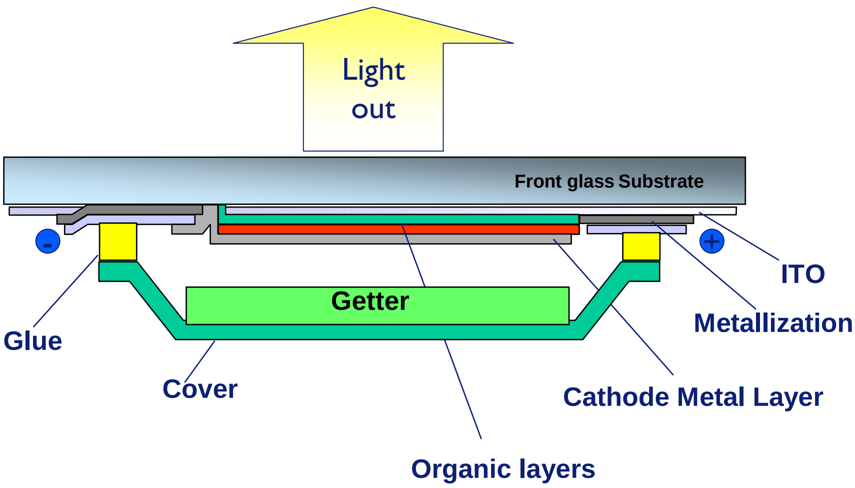
Organic LEDs - the principle



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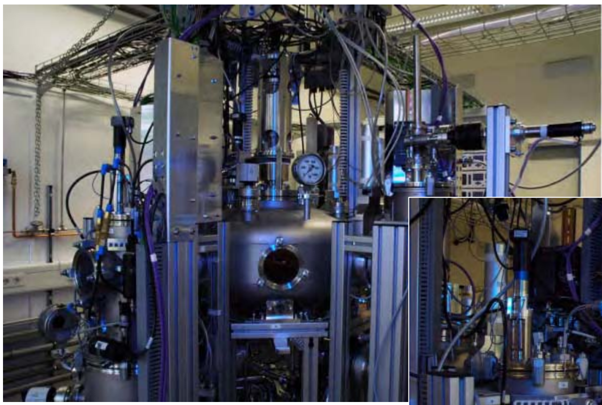
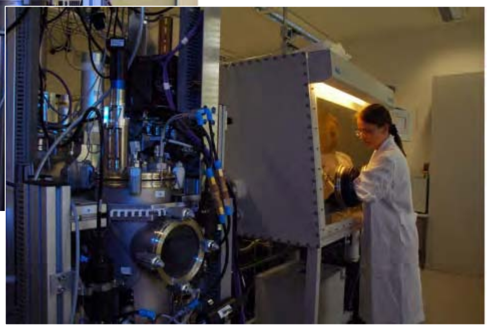
OLED Processing

- Octopus II startup (March 2006)



Glove box for loading/unloading



50 x 50 mm substrate size,
Extremely clean vacuum

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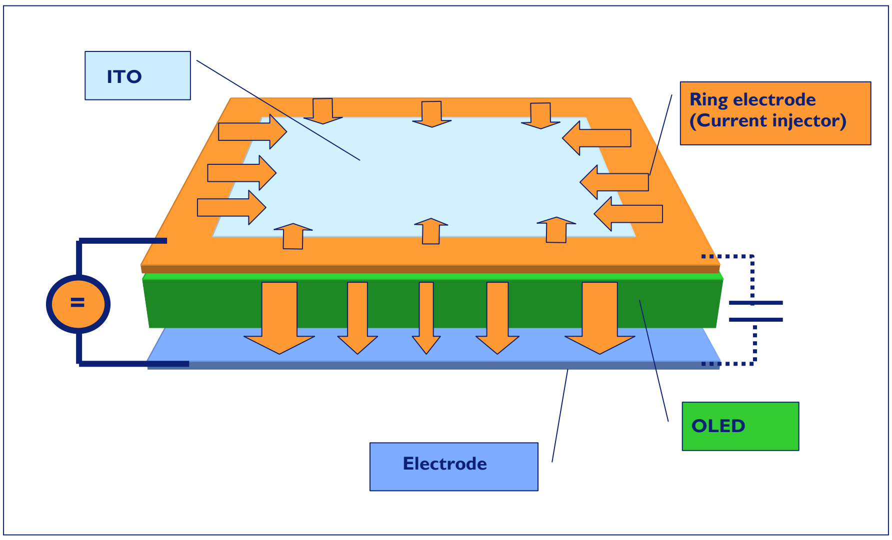
Non-uniform Current Flow in OLEDs



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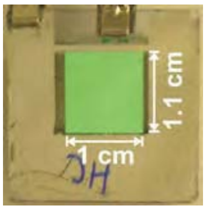
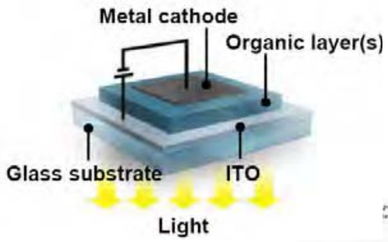
OLLA Result: ITO-free OLED device





A double emission green OLED on a polymer anode with an active area of 1.1 cm², using Baytron PH 500 from HC-Starck instead of Indium Tin Oxides (ITO). Route towards lower device costs.

OLLA works on larger size demonstration

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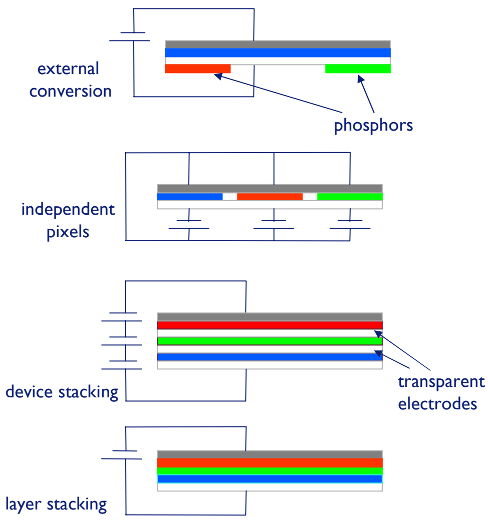
OLED structures for white



	Pro	Con
external conversion	• good CRI • simple to make	• relies on blue • colored off state
independent pixels	• good CRI • color variable	• difficult to make • inhomogeneous appearance
device stacking	• good CRI • robust design	• higher voltage • advanced process
layer stacking	• good CRI • simple to make	• fixed color • sensitive balance

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OLLA-Result: Color-tunable OLED

- General illumination with “dynamic light” enabled by OLED

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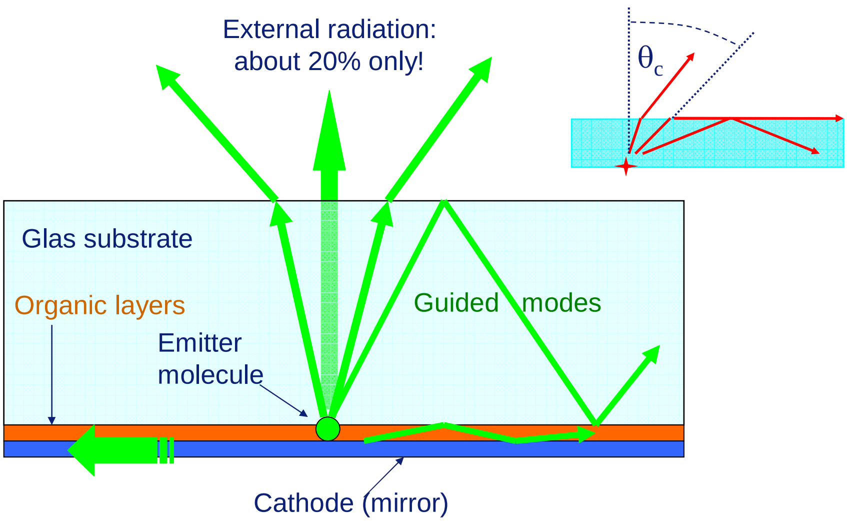
OLED Light Outcoupling



OLED Development Philips Lighting 29.11.2005
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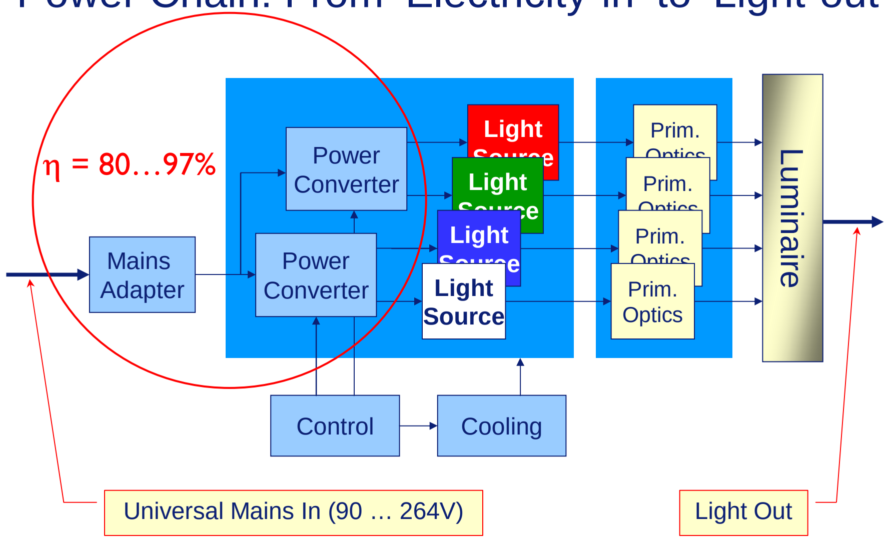
Power Chain: From ‘Electricity-in’ to ‘Light-out’



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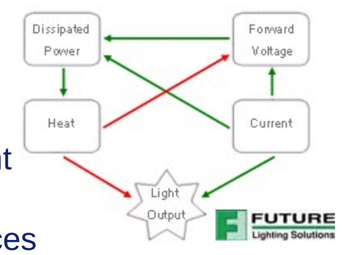
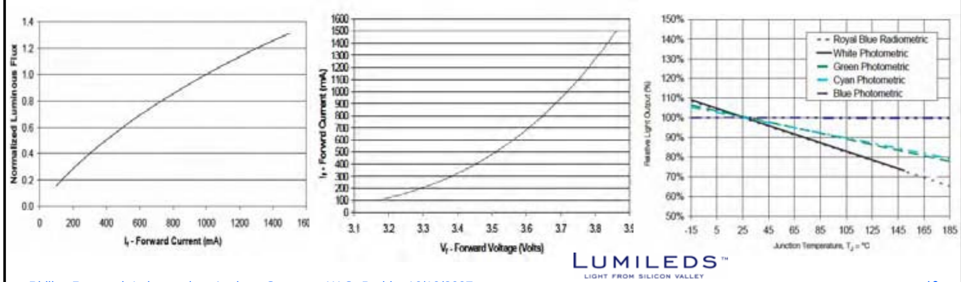
Optimization is a “Must”

- Many parameters impact overall performance
  - Color shift over temperature
  - Efficacy decay over drive current
  - Resulting color shift over drive current for composite light sources





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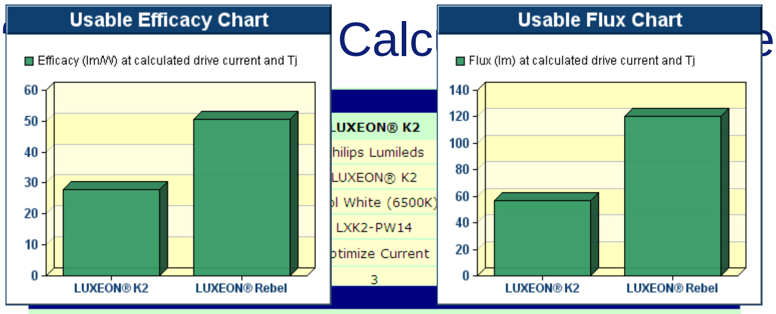

	LUXEON® K2	LUXEON® Rebel	
Calculated Drive Current:	611	777	(mA)
Calculated Forward Voltage:	3.36	3.06	(V)
Calculated LED Power Consumption:	2.05	2.37	(W)
Calculated Array Power Consumption:	6.15	7.12	(W)
Datasheet Junction-to-Case Rth:	9	10	(°C/W)
Calculated Junction Temperature:	120	135	(°C)
Calculated Usable LED Flux:	57	120	(lm)
Calculated Usable Array Flux:	171	361	(lm)
Calculated Usable Efficacy:	27.76	50.68	(lm/W)

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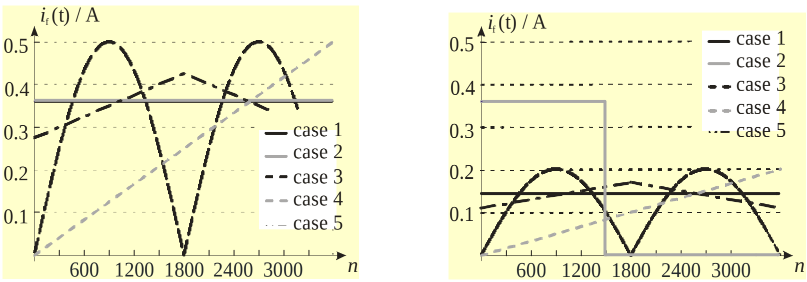
Evaluation of Drive Schemes



100% LED forward current *40% LED forward current*

- Some waveforms require overdriving for maximum light output
- Using PWM-dimming is least efficient
- With all other waveforms the efficiency increases as the luminous flux output is decreased (except for very low settings)
- DC driving with AM dimming yields optimum efficiency
- Superimposing a small ripple (*42% pp*) has no significant influence on the luminous efficiency (but significantly cheaper than DC)

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Driver Design Challenges

- Optimize design for reasonable use cases
  - Constant light output for RGB spot regardless of selected color
    Straightforward design: $I_{max} = I_{red} + I_{green} + I_{blue}$
    Optimized design: $I_{max} = 1/3\ I_{red} + 1/3\ I_{green} + 1/3\ I_{blue}$ (simplified)
  - Caveat: intelligent control needed for restriction of use cases
- Solid state light sources change placement paradigm
  - Multitude of light points
  - New applications like “atmosphere lighting”
  - Scalable area light sources demand scalable drivers
- Solid state light sources change user interface paradigm
  - Effect control instead of lamp control
  - Automatic “light scene rendering”
- Efficient, flexible yet convenient control is needed
  - Special attention to standby power consumption

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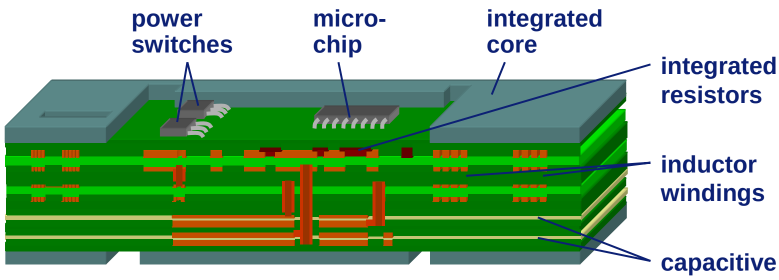
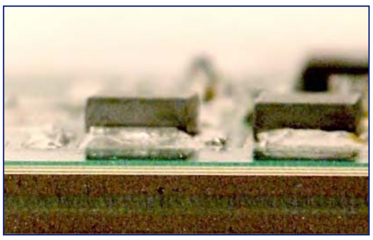
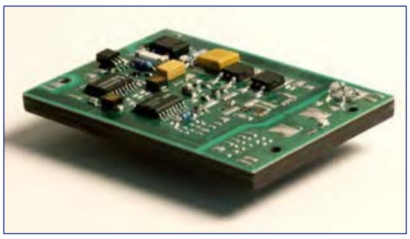
Driver Design Challenges – New Form Factors



emPIC: embedded Passives Integrated Circuits





60W Offline emPIC LED driver

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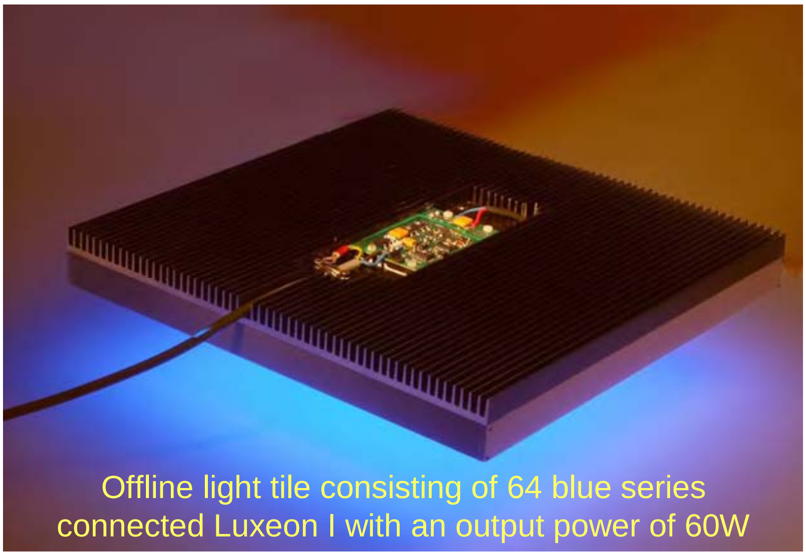
Light tile demonstrator



Offline light tile consisting of 64 blue series connected Luxeon I with an output power of 60W

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Conclusions

- LEDs and OLEDs are getting quite efficient
  - Yet, overall system optimization is crucial
- Paradigm shifts and new applications demand new solutions
  - High level of control, automation required
  - Unprecedented freedom of form factors
- Lifetime of light source and electronics need to be matched
- More challenges for luminaire design than ever
  - Close cooperation required with light source manufacturer and electronics supplier
- Still a heap of research challenges ahead

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Three-Gorges Power Plant

The Largest Hydraulic Power Plant in the World

- Construction from 1994 - 2014
- Total investment 200 B RMB (US$24 B)
- Annual output 85 Billion KWh

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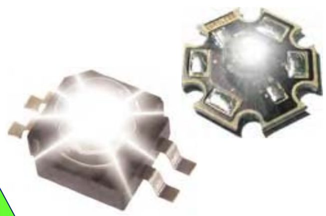
Solid-State Lighting – The Clean Alternative



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Thank you!

Phosphors – Key Materials for Solid-State Lighting

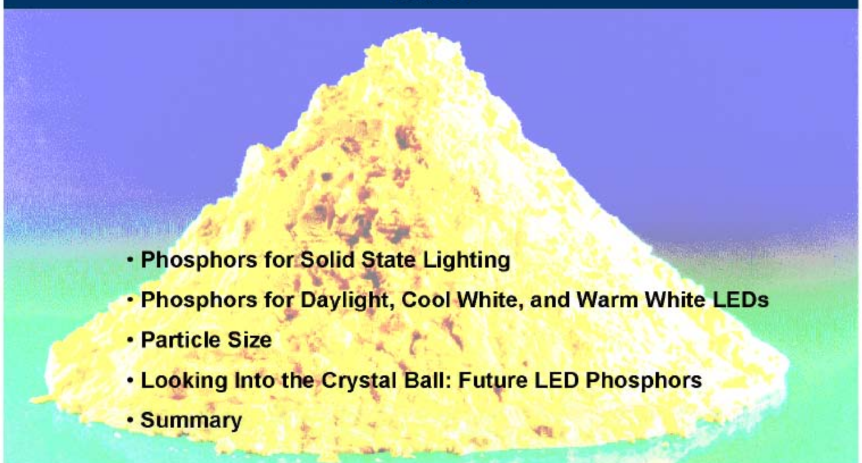
M. Zachau, T. Fiedler , and F. Jermann

Workshop “LEDs in General Lighting”, EU JRC, Ispra, May 3-4, 2007

OSRAM

Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary

Outline



- Phosphors for Solid State Lighting
- Phosphors for Daylight, Cool White, and Warm White LEDs
- Particle Size
- Looking Into the Crystal Ball: Future LED Phosphors
- Summary

LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 1
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt

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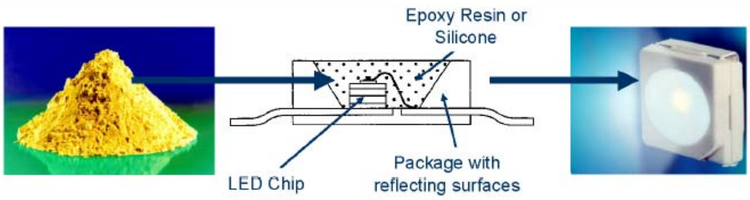
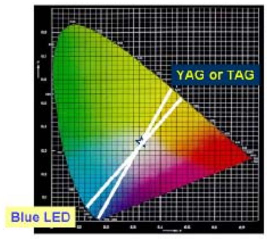
Phosphors for Solid State Lighting





Phosphor Color Required

	chip	phosphor λ_{dom}
6000 K	450-470 nm	570 - 573 nm

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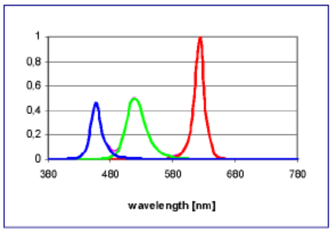
White LEDs: Phosphor Conversion versus Multi-Chip

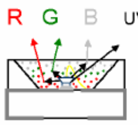
mc- LEDs offer color tunability.
Adjusted illumination from sunset to sundown.

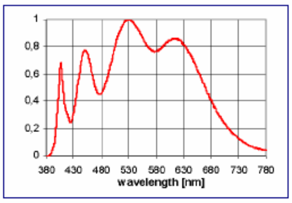


	pc-LEDs	mc-LEDs
Efficiency	o high	+ higher?
Costs	+ high	- higher
Lumen*years/ $?	+ medium	- low
Color drift (T, I, t)	+ small	- medium
CRI	+ > 90 possible	- < 90 but...

OSRAM

White pc-LED: UV versus Blue Pump LED





	UV-LED	blue LED
	with phosphor conversion	
Efficiency	o high ?	+ higher
Lum. Equivalent	o medium	+ high
Quantum Loss	o medium	+ small
Chip Efficiency	?	+ high
Stability	- medium	+ higher
Costs	- higher	+ high
Color drift	+ small	- medium
CRI @ max LPW	+ high	o depends on CCT

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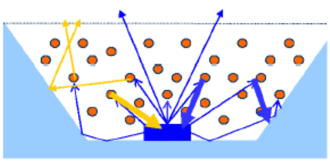
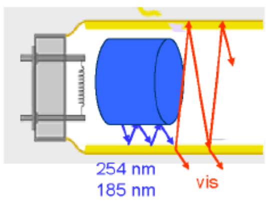
Phosphor Requirements Depend on Application





Multiple reflections cause losses in LEDs
=> High absorption required in LEDs

...but not in fluorescent lamps

OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Phosphor Requirements Depend on Application
General Lighting
Mood Lighting
Warm White
Thermal Requirements?
Color Rendering & CCT?
Flux Levels?
Head Lamps
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 6
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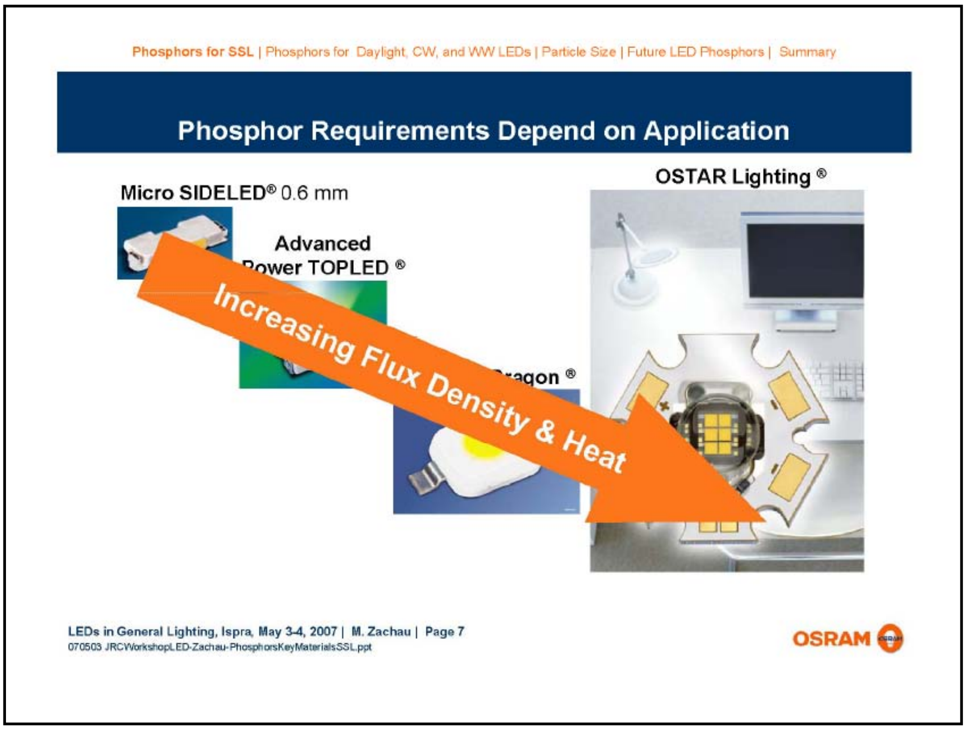
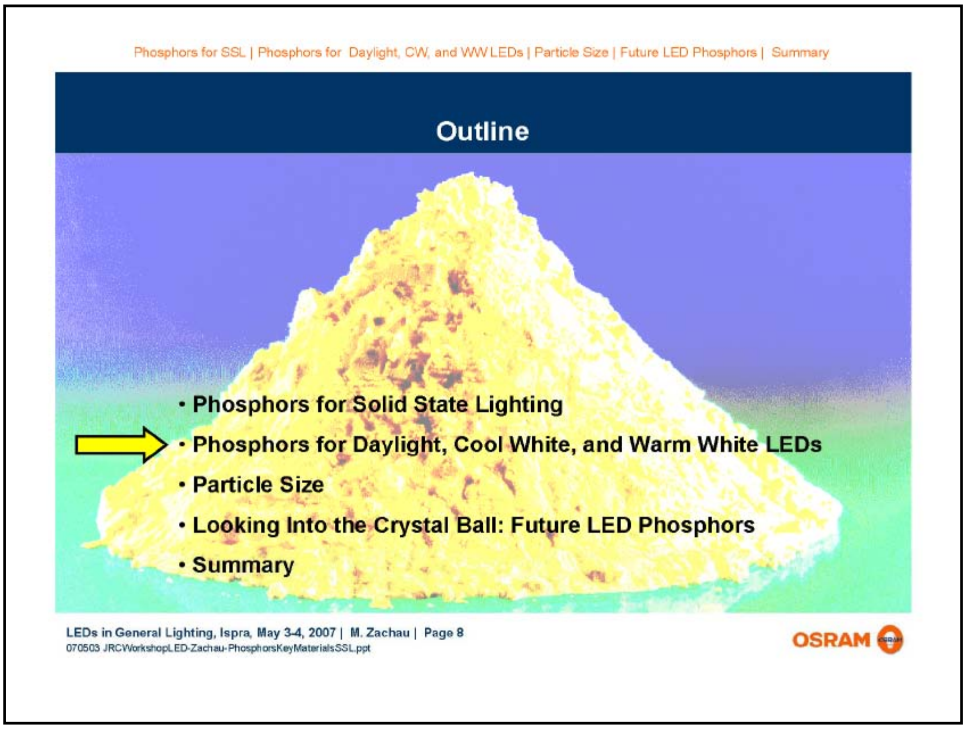

Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Phosphor Requirements Depend on Application
Micro SIDELED® 0.6 mm
Advanced
OSTAR Lighting ®
Increasing Flux Density & Heat
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 7
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Outline
• Phosphors for Solid State Lighting
• Phosphors for Daylight, Cool White, and Warm White LEDs
• Particle Size
• Looking Into the Crystal Ball: Future LED Phosphors
• Summary
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 8
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
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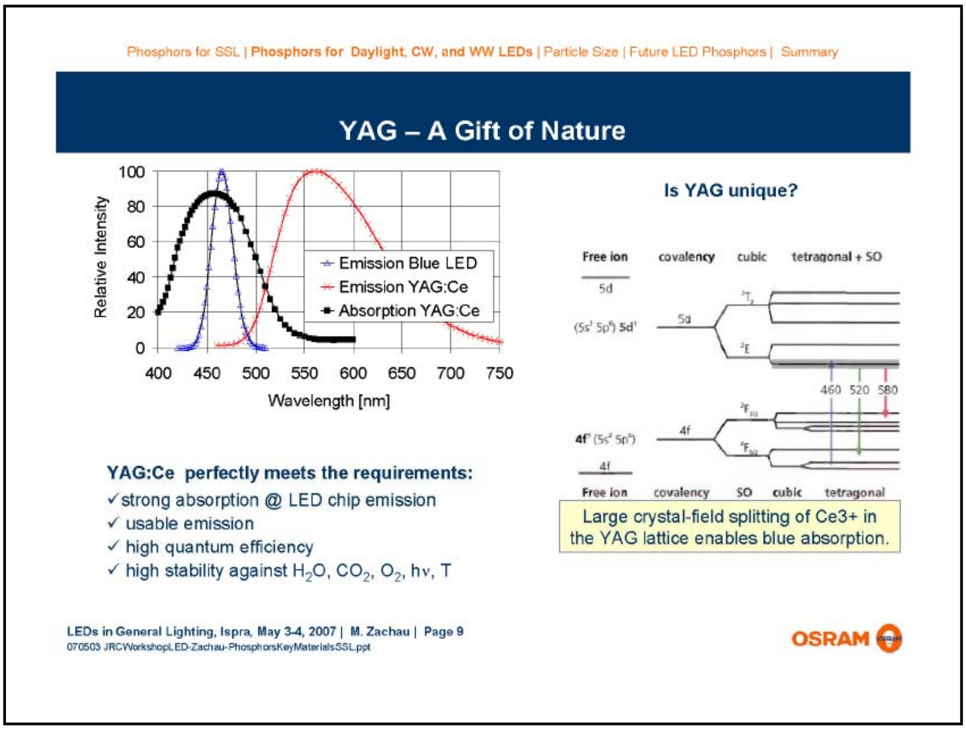
Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
YAG – A Gift of Nature
Relative Intensity
100
80
60
40
20
0
400 450 500 550 600 650 700 750
Wavelength [nm]
Emission Blue LED
Emission YAG:Ce
Absorption YAG:Ce
Is YAG unique?
Free ion
covalency
cubic
tetragonal + SO
5d
(5s² 5p⁶) 5d¹
5d
4f¹ (5s² 5p⁶)
4f
460 520 580
Free ion
covalency
SO
cubic
tetragonal
Large crystal-field splitting of Ce3+ in the YAG lattice enables blue absorption.
YAG:Ce perfectly meets the requirements:
✓strong absorption @ LED chip emission
✓ usable emission
✓ high quantum efficiency
✓ high stability against H_2O, CO_2, O_2, hν, T
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 9
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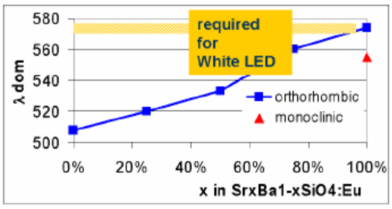
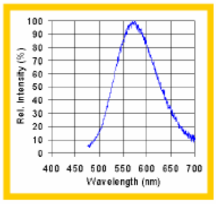
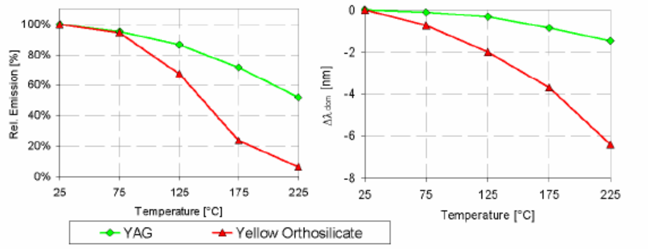
Yellow Orthosilicates for White LEDs







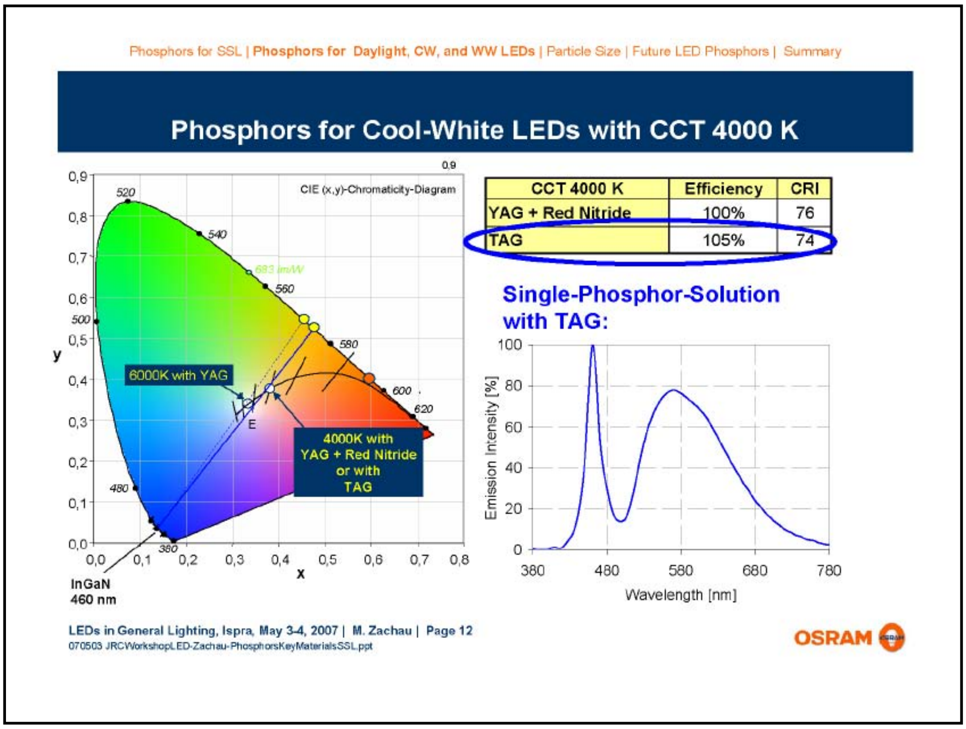
High-Power / Temperature Application I: YAG

Efficiency =
Absorption *
Quantum Efficiency *
Luminous Efficiency *
Temperature Factor

	Efficiency		
	25 °C	75 °C	125 °C
YAG	100%	96%	88%
Yellow Orthosilicate	96%	90%	64%

SSL requires phosphors with high temperature stability!

...but this may also work


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Phosphors for Cool-White LEDs with CCT 4000 K
CIE (x,y)-Chromaticity-Diagram
6000K with YAG
4000K with YAG + Red Nitride or with TAG
InGaN 460 nm
CCT 4000 K | Efficiency | CRI
YAG + Red Nitride | 100% | 76
TAG | 105% | 74
Single-Phosphor-Solution with TAG:
Emission Intensity [%]
Wavelength [nm]
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 12
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
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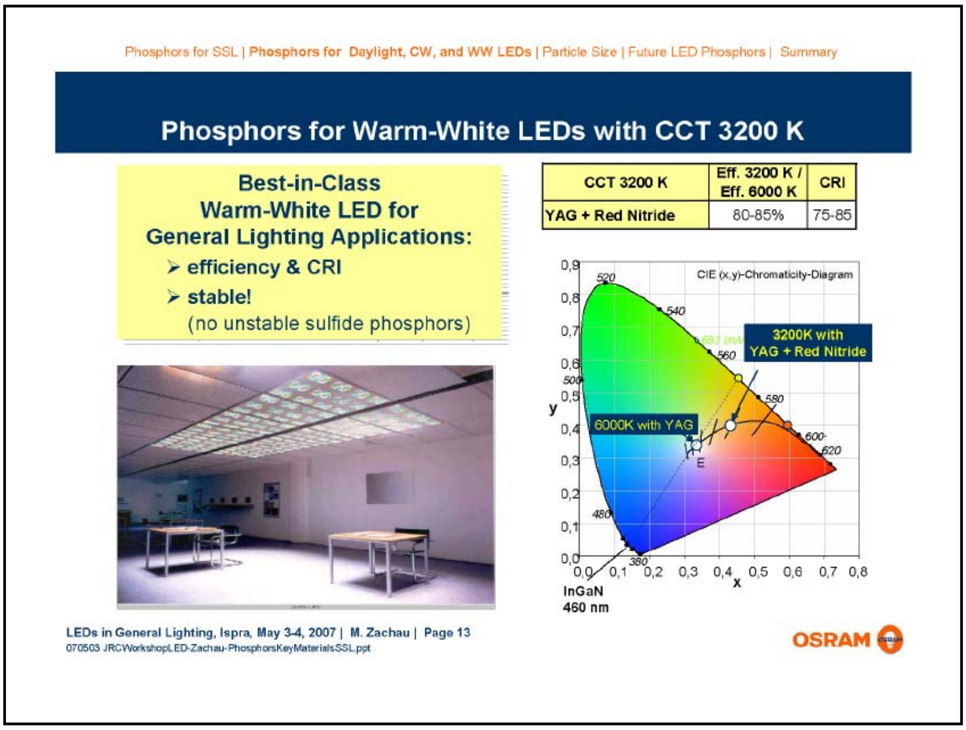
Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Phosphors for Warm-White LEDs with CCT 3200 K
Best-in-Class Warm-White LED for General Lighting Applications:
➢ efficiency & CRI
➢ stable!
(no unstable sulfide phosphors)
CCT 3200 K | Eff. 3200 K / Eff. 6000 K | CRI
YAG + Red Nitride | 80-85% | 75-85
CIE (x,y)-Chromaticity-Diagram
3200K with YAG + Red Nitride
6000K with YAG
InGaN 460 nm
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 13
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
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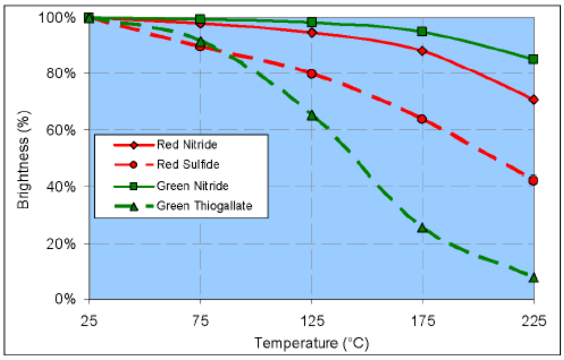
High-Power / Temperature Application II: Nitride Phosphors



Red & Green Nitride phosphors are most stable at high temperature
(perfect for low <u>and</u> high-Wattage applications).

... and they are chemically stable too.

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Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary

High-Power / Temperature Application II: Nitride Phosphors

Red Nitrides

- **OSRAM**
  - US 6649946 and 6682663 (Nov 30, 1999)
- **Lumileds**
  - WO 2004/055910 A1(Dec 13, 2002)
- **Nichia**
  - EP 1433831 (Mar 22, 2003)

Green Nitrides

- **OSRAM**
  - WO 2004/029177 and WO 2004/030109 (Sep 24, 2002)
- **Lumileds**
  - US 6717353 (Oct 14, 2002)
- **Nichia**
  - EP 01571194 (Oct 16, 2002)

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Phosphors for Warm-White LEDs with CCT 3200 K

Is there a single-phosphor solution for Warm-White LED ?

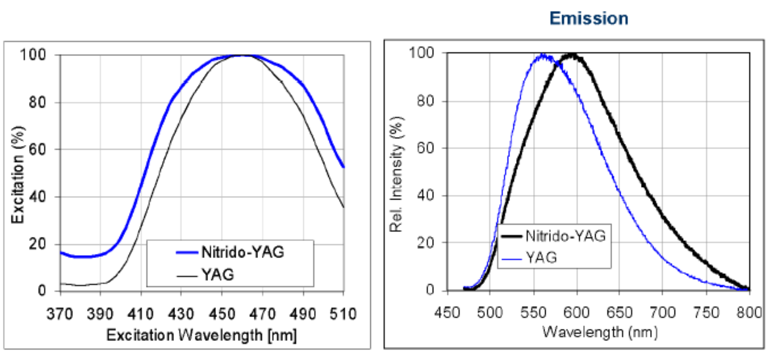
- ✓ **lower production costs (processing, production yield)**
- ✓ **lower scattering and absorption losses → higher efficiency**

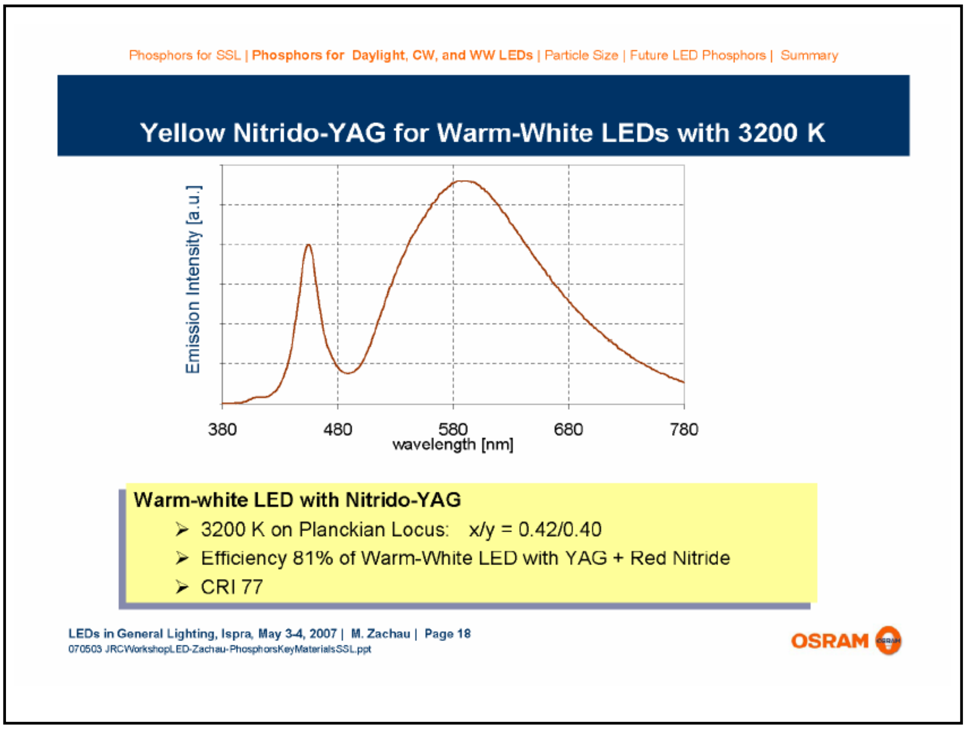
→ Look for Yellow-Orange Emitting Phosphors

Yellow Nitrido-YAG for Warm-White LEDs with 3200 K

Novel phosphor has been discovered (US2005/0242329):

Nitrido-YAG **Si+N substitute for Al+O**




Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Yellow Nitrido-YAG for Warm-White LEDs with 3200 K
Emission Intensity [a.u.]
380
480
580
680
780
wavelength [nm]
Warm-white LED with Nitrido-YAG
3200 K on Planckian Locus: x/y = 0.42/0.40
Efficiency 81% of Warm-White LED with YAG + Red Nitride
CRI 77
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 18
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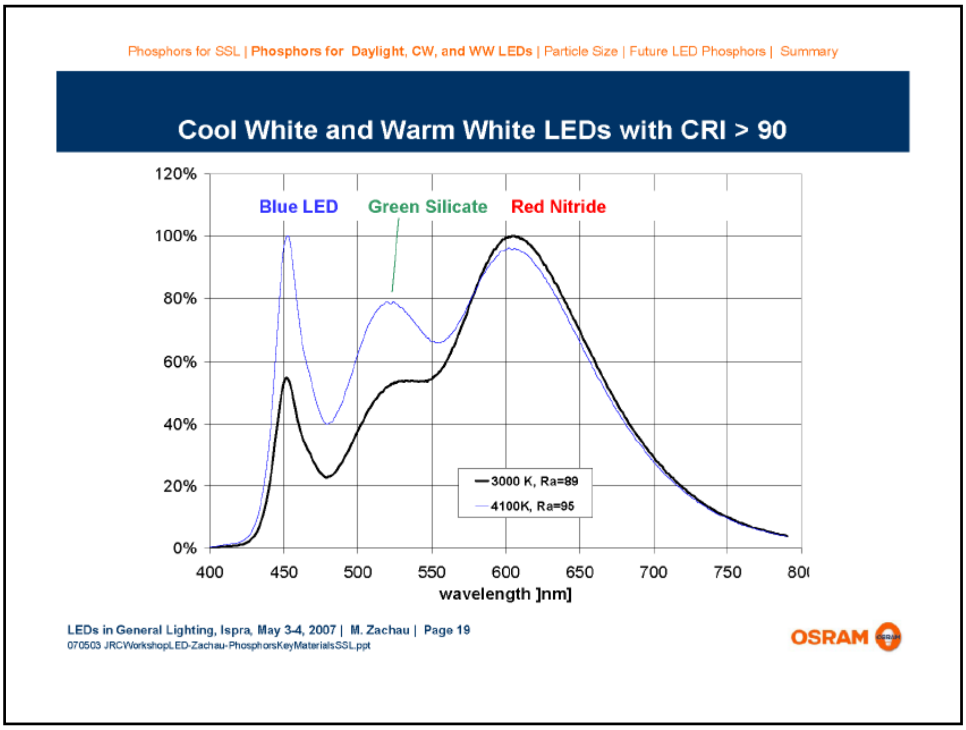
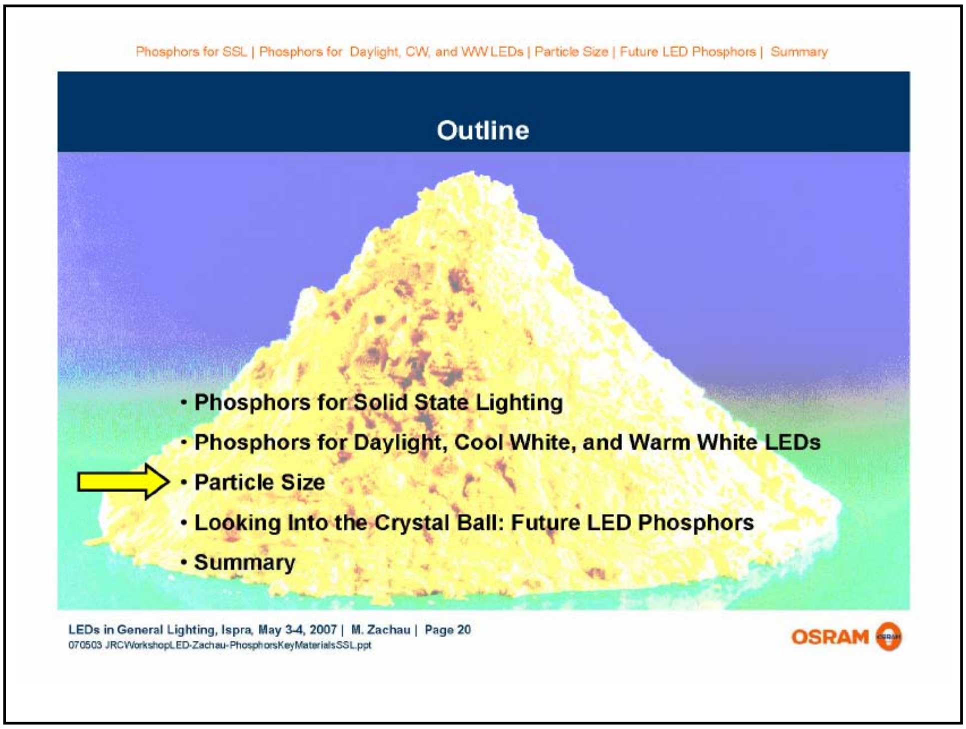
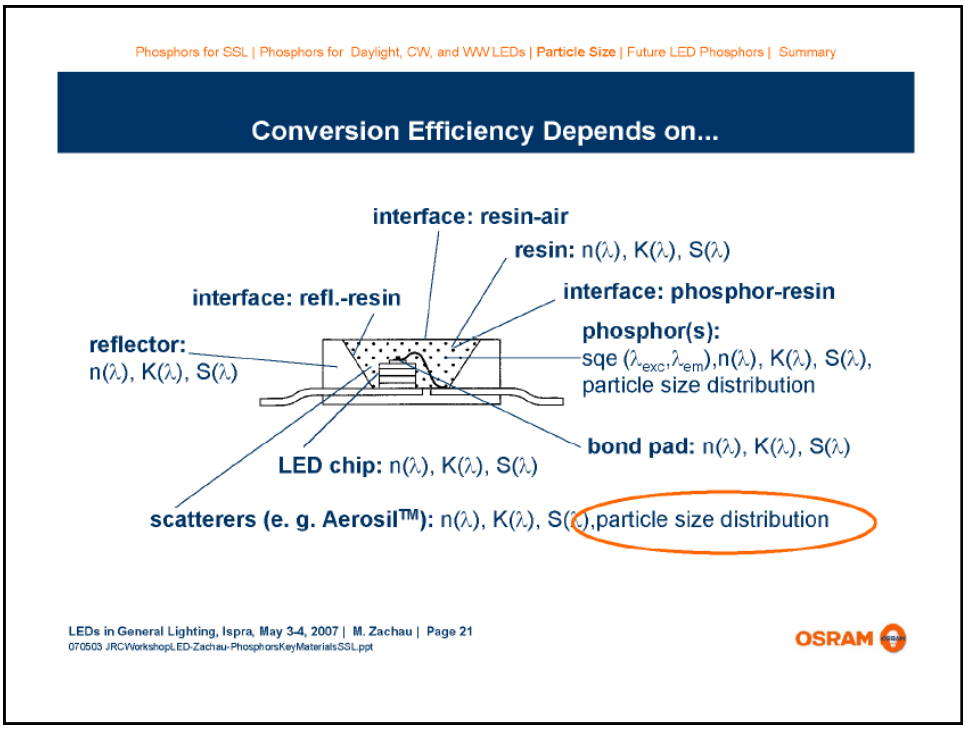
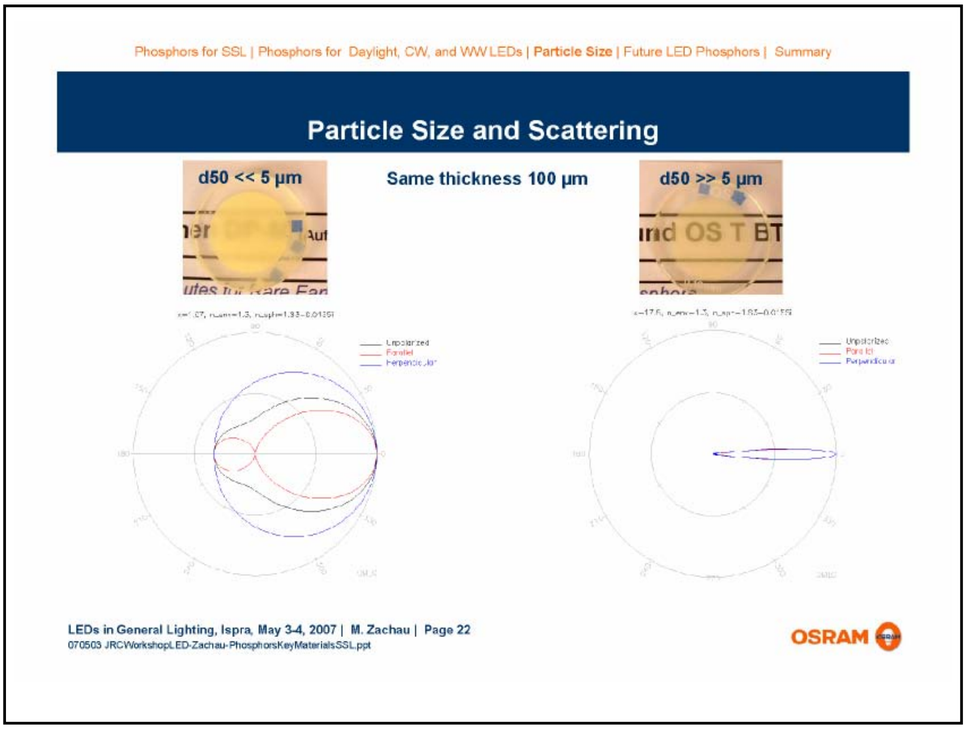
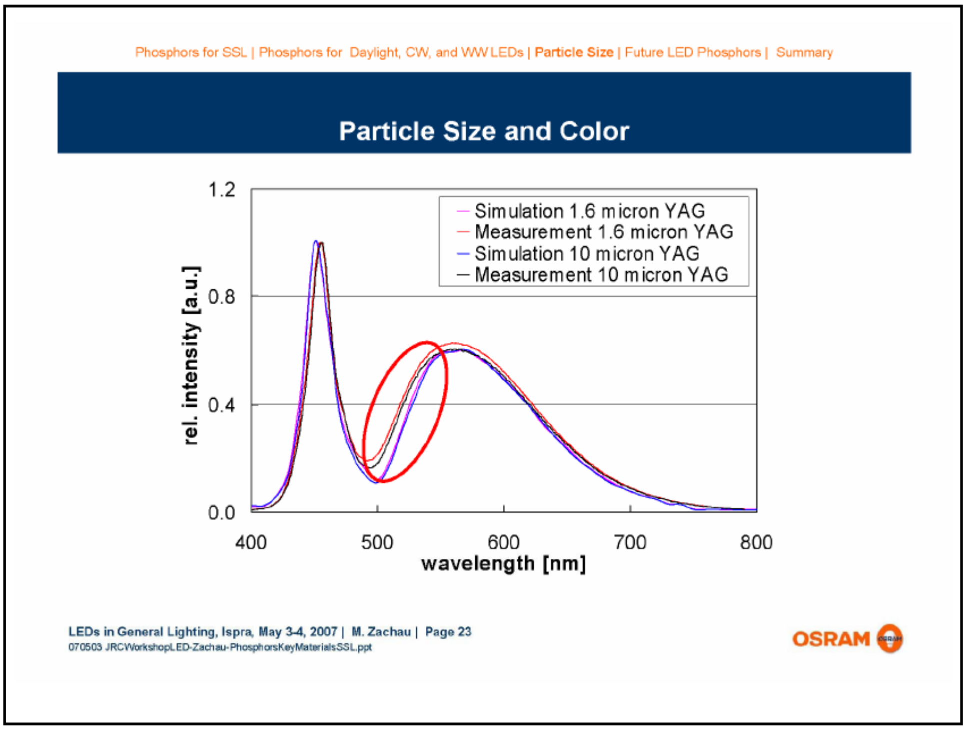
OSRAM

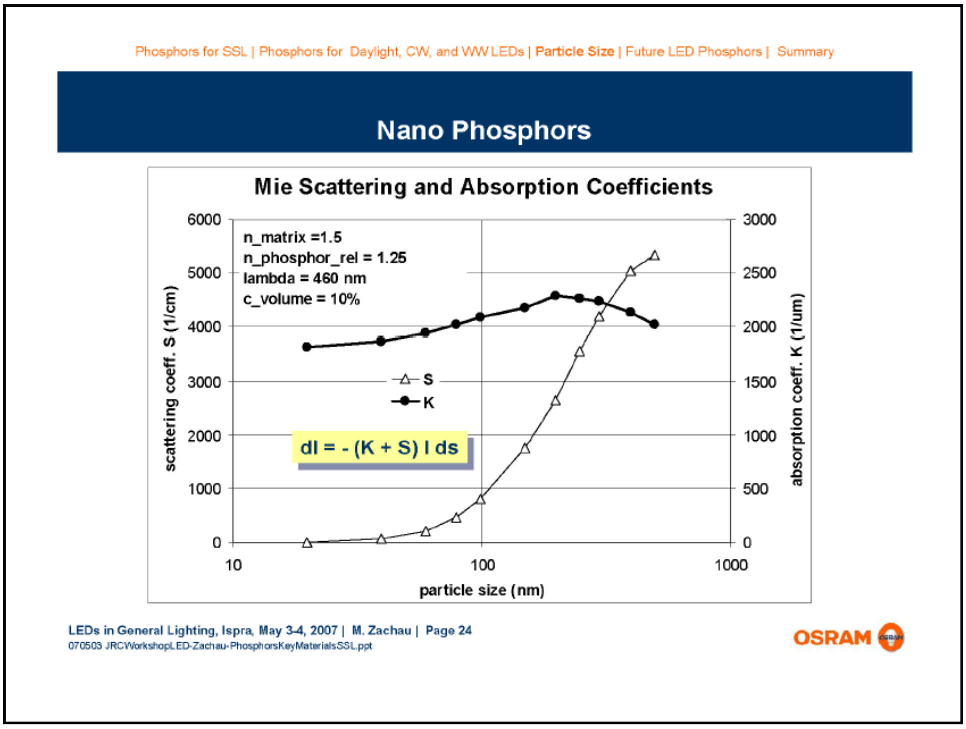

Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Cool White and Warm White LEDs with CRI > 90
120%
100%
80%
60%
40%
20%
0%
Blue LED
Green Silicate
Red Nitride
3000 K, Ra=89
4100K, Ra=95
400
450
500
550
600
650
700
750
80(
wavelength]nm]
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 19
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM

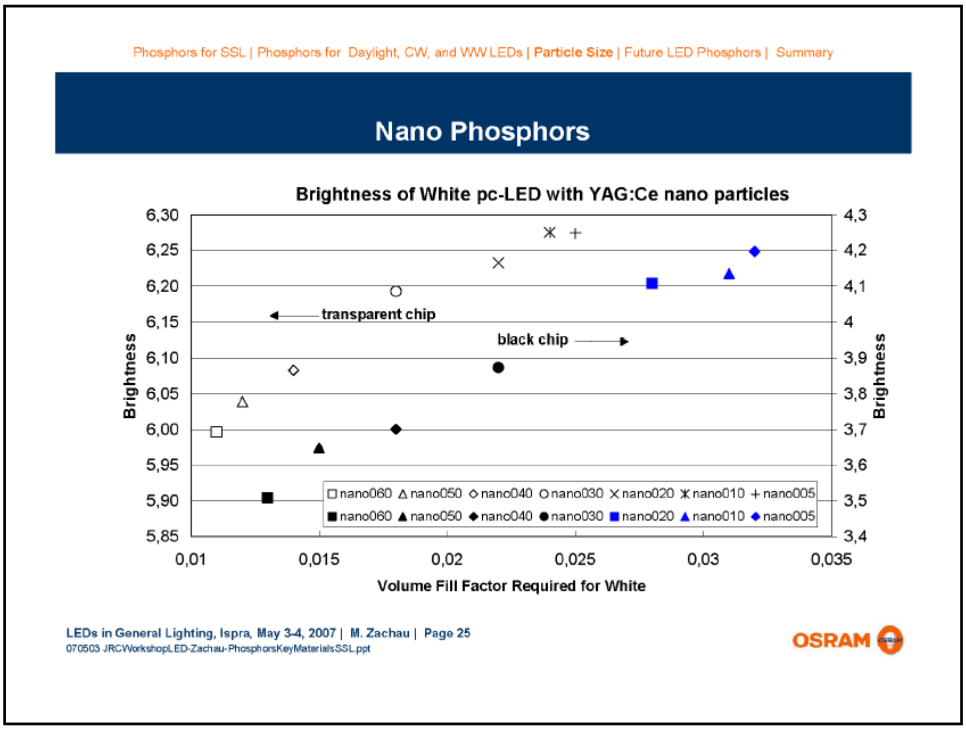

Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Outline
• Phosphors for Solid State Lighting
• Phosphors for Daylight, Cool White, and Warm White LEDs
• Particle Size
• Looking Into the Crystal Ball: Future LED Phosphors
• Summary
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 20
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM

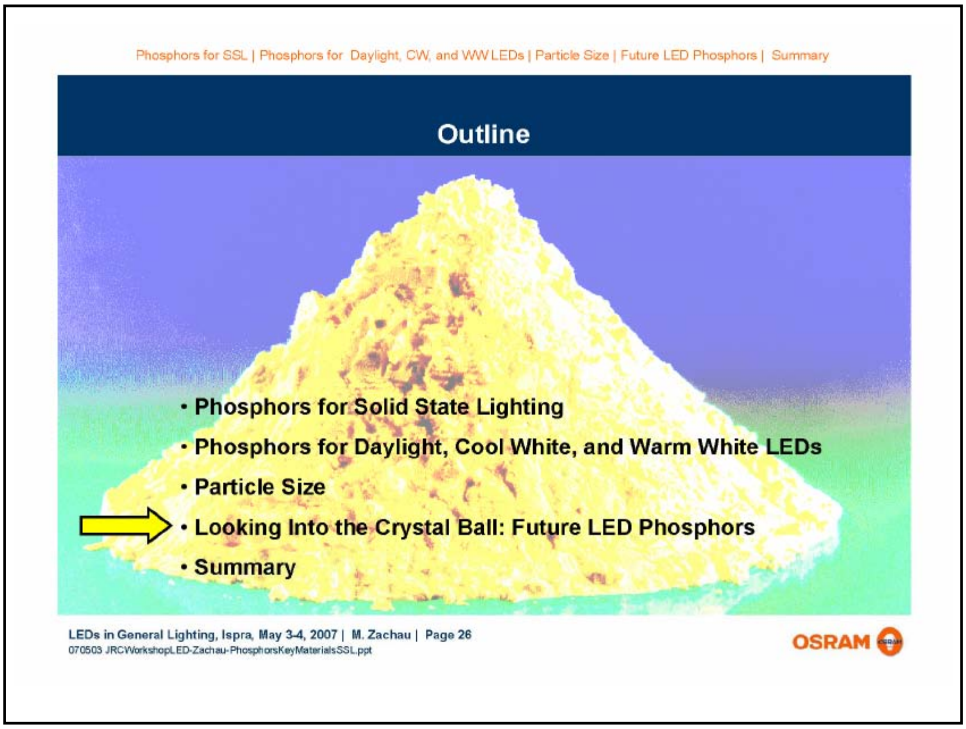

Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Conversion Efficiency Depends on...
interface: resin-air
resin: n(λ), K(λ), S(λ)
interface: refl.-resin
interface: phosphor-resin
reflector:
n(λ), K(λ), S(λ)
phosphor(s):
sqe (λexc,λem),n(λ), K(λ), S(λ),
particle size distribution
bond pad: n(λ), K(λ), S(λ)
LED chip: n(λ), K(λ), S(λ)
scatterers (e. g. Aerosil™): n(λ), K(λ), S(λ),particle size distribution
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 21
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Particle Size and Scattering
d50 << 5 µm
Same thickness 100 µm
d50 >> 5 µm
Unpolarized
Parallel
Perpendicular
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 22
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Particle Size and Color
Simulation 1.6 micron YAG
Measurement 1.6 micron YAG
Simulation 10 micron YAG
Measurement 10 micron YAG
rel. intensity [a.u.]
1.2
0.8
0.4
0.0
400
500
600
700
800
wavelength [nm]
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 23
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Nano Phosphors
Mie Scattering and Absorption Coefficients
n_matrix =1.5
n_phosphor_rel = 1.25
lambda = 460 nm
c_volume = 10%
S
K
dI = - (K + S) I ds
scattering coeff. S (1/cm)
absorption coeff. K (1/um)
particle size (nm)
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 24
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Nano Phosphors
Brightness of White pc-LED with YAG:Ce nano particles
transparent chip
black chip
nano060 nano050 nano040 nano030 nano020 nano010 nano005
Brightness
Volume Fill Factor Required for White
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 25
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
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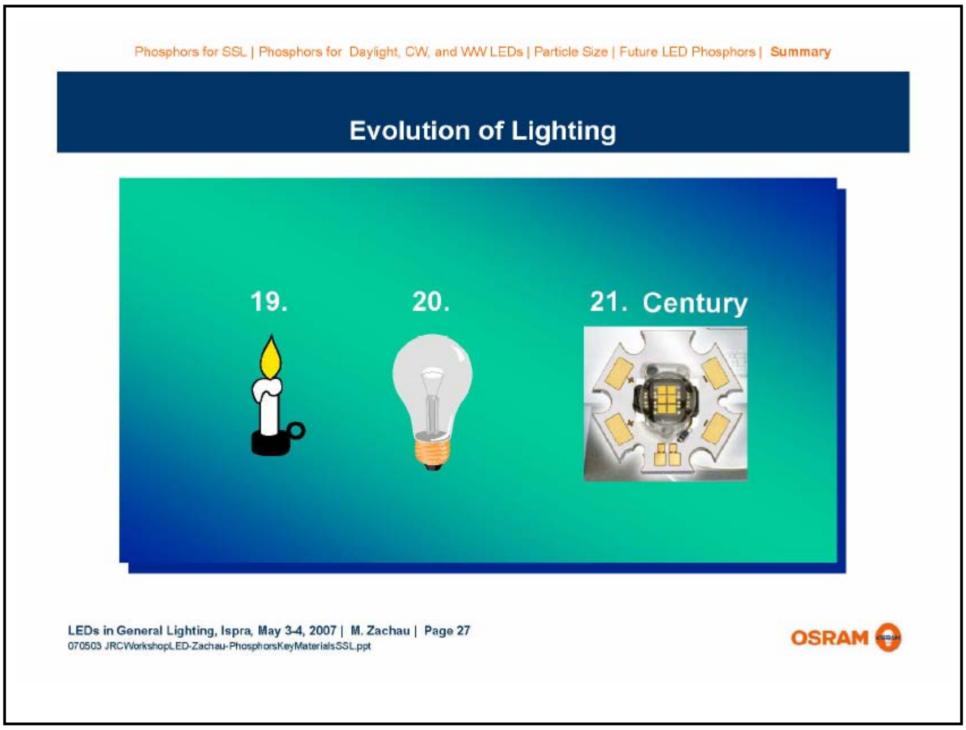
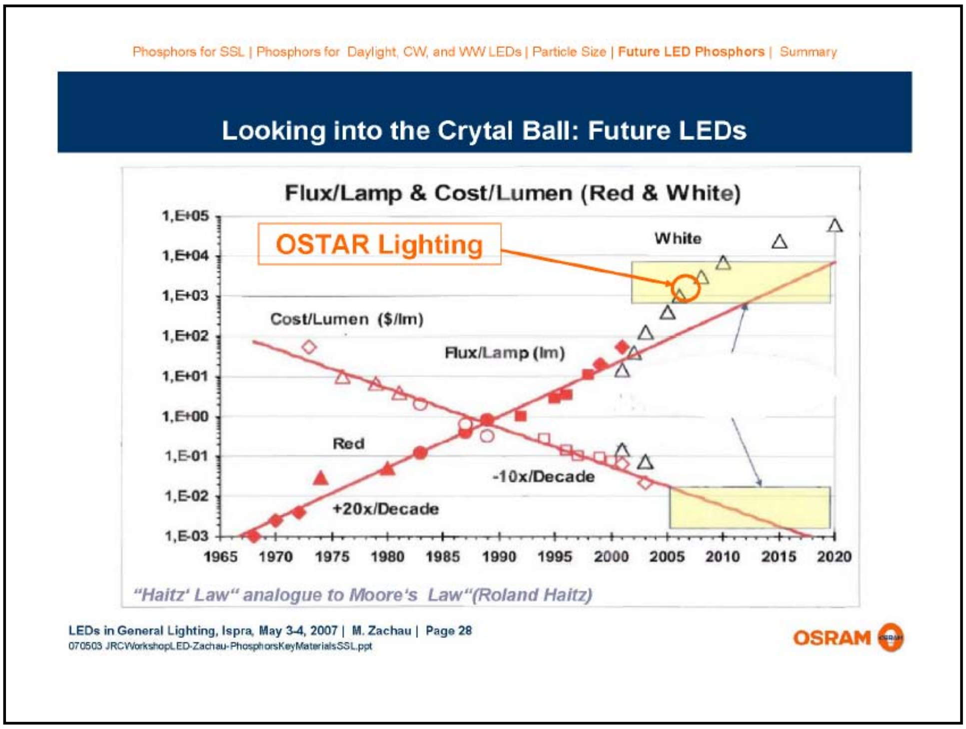
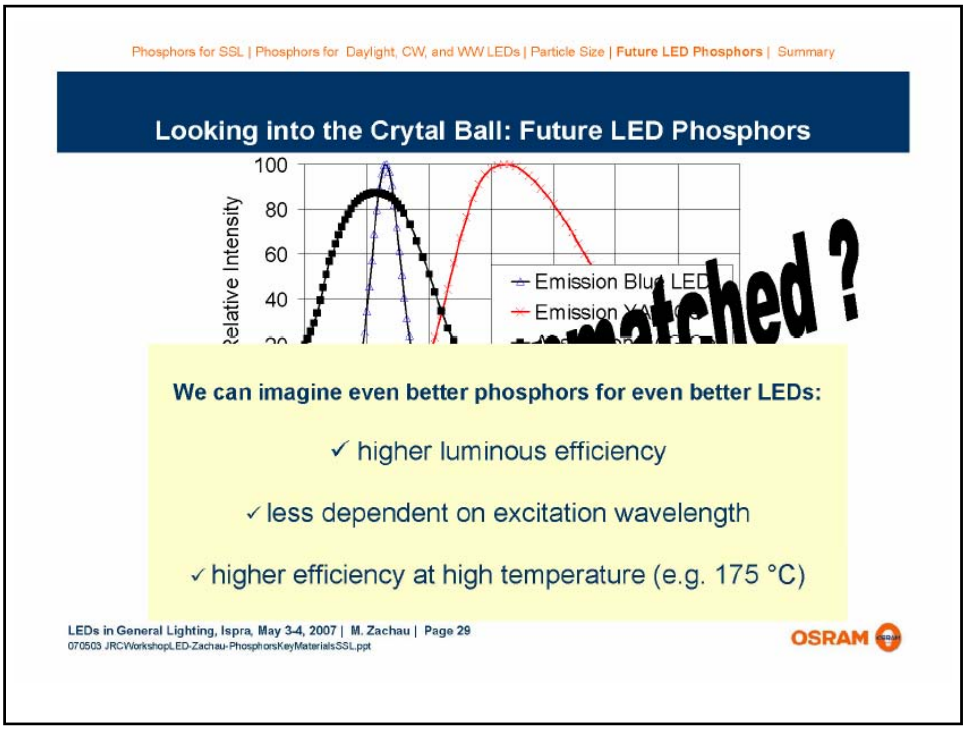
• Looking Into the Crystal Ball: Future LED Phosphors
• Summary
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 26
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Evolution of Lighting
19.
20.
21. Century
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 27
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM

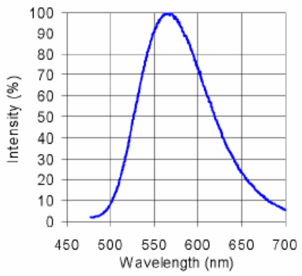

Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Looking into the Crytal Ball: Future LEDs
Flux/Lamp & Cost/Lumen (Red & White)
OSTAR Lighting
White
Cost/Lumen ($/lm)
Flux/Lamp (lm)
Red
-10x/Decade
+20x/Decade
1,E+05
1,E+04
1,E+03
1,E+02
1,E+01
1,E+00
1,E-01
1,E-02
1,E-03
1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
"Haitz' Law" analogue to Moore's Law"(Roland Haitz)
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 28
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM


Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | Future LED Phosphors | Summary
Looking into the Crytal Ball: Future LED Phosphors
100
80
60
40
We can imagine even better phosphors for even better LEDs:
✓ higher luminous efficiency
✓ less dependent on excitation wavelength
✓ higher efficiency at high temperature (e.g. 175 °C)
LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 29
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt
OSRAM

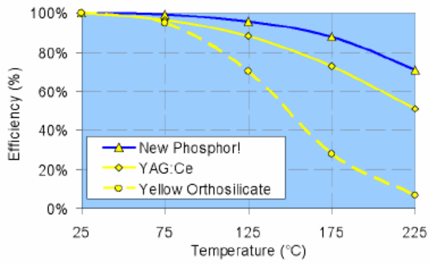
Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | **Future LED Phosphors** | Summary

Looking into the Crytal Ball: Future LED Phosphors

Garnet Phosphor? Nitride Phosphor? → New phosphor !



- ✓ emission color similar to YAG but with higher luminous efficiency
- ✓ excitable with UV and blue LEDs
- ✓ high temperature stability… even better than YAG



… more soon

LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 30
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt

OSRAM

Phosphors for SSL | Phosphors for Daylight, CW, and WW LEDs | Particle Size | **Future LED Phosphors** | Summary

Looking into the Crytal Ball: Phosphors for UV-LEDs

Most Eu^{2+}-based LED phosphors...
...are even more efficient when excited by UV-LEDs!

Don't expect too much from fluorescent lamp phosphors.

They are doped with Eu^{3+}, Tb^{3+}, Mn^{4+} or Mn^{2+} and …
Typically have narrow emission bands and high luminous efficiency, but

- **weak absorption**
  →multiple scattering losses
- **long decay times:**
  → expect saturation effects!
- **sensitized phosphors:**
  → efficiency & color strongly temperature dependent

LEDs in General Lighting, Ispra, May 3-4, 2007 | M. Zachau | Page 31
070503 JRCWorkshopLED-Zachau-PhosphorsKeyMaterialsSSL.ppt

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Summary

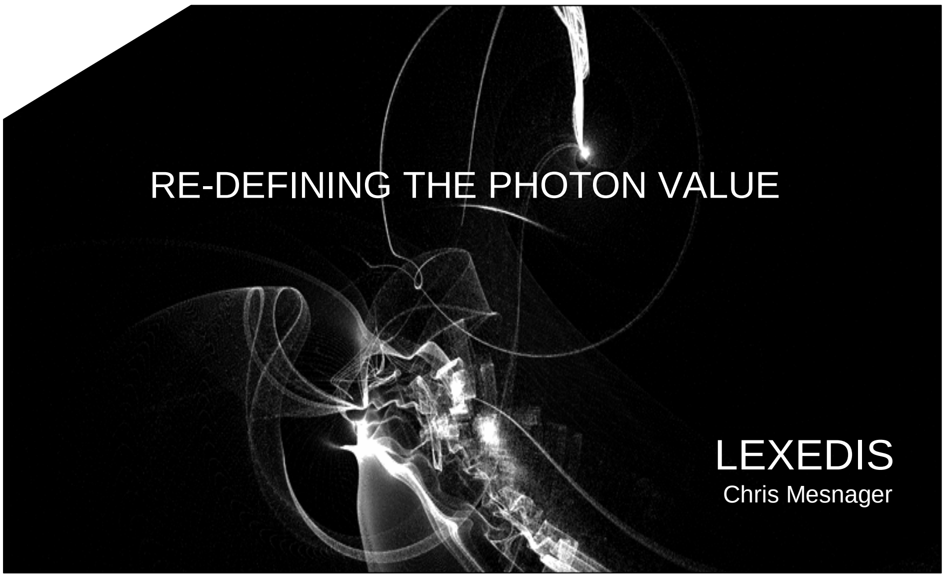
- **for (Daylight) White LEDs (5500-6500 K)**
  - Aluminum-based Garnets are in the pole position
  - Orthosilicates: the runner-up has serious limitations
- **for Cool White and Warm White LEDs (4000 K and below)**
  - Cool White: TAG is efficient and easy to use
  - Warm White: Garnet + Red Nitride is most efficient
  - Cool and Warm White with CRI > 90 possible with Chlorosilicate and Red Nitride
  - Green and Red Nitride Phosphors for high-power SSL applications
- **Particle Size**
  - affects color point, homogeneity, and efficiency => package dependent optimization
  - nano phosphors: particle size << 50 nm required for high efficiency
- **Looking into the Crystal Ball...**
  - SSL starting soon! today?
  - YAG will not be the final choice!
  - pc-LEDs with UV-pump?

Acknowledgement

OSRAM OS
K. Petersen
R. Schwarz
J. Strauss

Thank You For Your Attention

ISPRA 2007



LEXEDIS Lighting GmbH

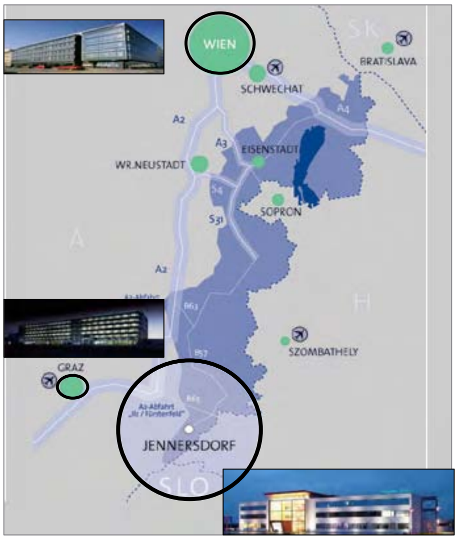
PROFILE

- EU Top **Luminaire maker**
- **Sales**: Euro 1.2 Bio.
- **Authority** in lighting
- **Strategic** focus on LED

- **Toyota** Group company
- **Sales**: Euro 4 Bio.
- Pioneer of **InGaN** technology
- Leading **InGaN** wafer vendor

2 | Corporate Profile 16/10/2007 LEXEDIS

LEXEDIS Lighting GmbH



OPTO ALLIANCE

- Sales : **185 Mio**. Euro
- Employees: **300**
- R&D centres : **3**
- *InGaN* Wafer fabs : **2** (Japan)
- Packaging facilities: **2**
- Granted patents: over **2500**
- Proprietary phosphour: BOSE
- Core emitter capacity: 2 **Bio.pcs**/year

3 | Corporate Profile 16/10/2007 LEXEDIS

PERCEPTION OF LIGHT

FROM DIVINITY…

- Sun God **Horakhty** (900 BC)
- **Divine** phenomenon
- **Light** symbolises purity, beauty and power
- Subject of **veneration**

…TO COMMODITY

- Symbol of '' **Consumer** God ''
- Euro **0.99** '' Bulb culture''
- **Light** is a basic need
- Source of energy **waste**

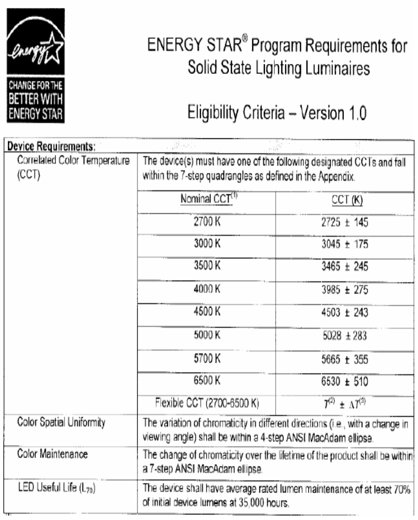
4 | Corporate Profile 16/10/2007 LEXEDIS

PERCEPTION OF LED

- Basic **photon** emitter
- Inferior White light **quality**
- Downgraded to ‘’**Commodity**’’ value
- **Complexity** in Design and Integration
- Expensive proposition
- Enabling technology for **Energy** saving

5 | Corporate Profile | 16/10/2007 | LEXEDIS

WHITE LIGHT QUALITY (ANSI Standard MacAdam-Ellipse 4)



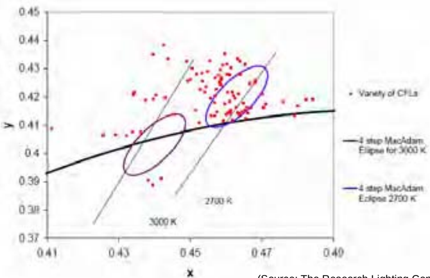
CHANGE FOR THE BETTER WITH ENERGY STAR

ENERGY STAR® Program Requirements for Solid State Lighting Luminaires

Eligibility Criteria – Version 1.0

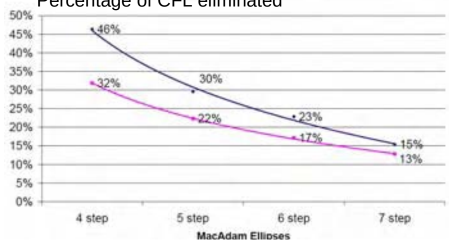
Device Requirements:		
Correlated Color Temperature (CCT)	The device(s) must have one of the following designated CCTs and fall within the 7-step quadrangles as defined in the Appendix.	
	Nominal CCT[1]	CCT (K)
	2700 K	2725 ± 145
	3000 K	3045 ± 175
	3500 K	3465 ± 245
	4000 K	3985 ± 275
	4500 K	4503 ± 243
	5000 K	5028 ± 283
	5700 K	5665 ± 355
	6500 K	6530 ± 510
	Flexible CCT (2700-6500 K)	$T^{(2)} \pm \Delta T^{(3)}$
Color Spatial Uniformity	The variation of chromaticity in different directions (i.e., with a change in viewing angle) shall be within a 4-step ANSI MacAdam ellipse.	
Color Maintenance	The change of chromaticity over the lifetime of the product shall be within a 7-step ANSI MacAdam ellipse.	
LED Useful Life (L_{70})	The device shall have average rated lumen maintenance of at least 70% of initial device lumens at 35,000 hours.	

Wide variations in CCT and chromaticity coordinates



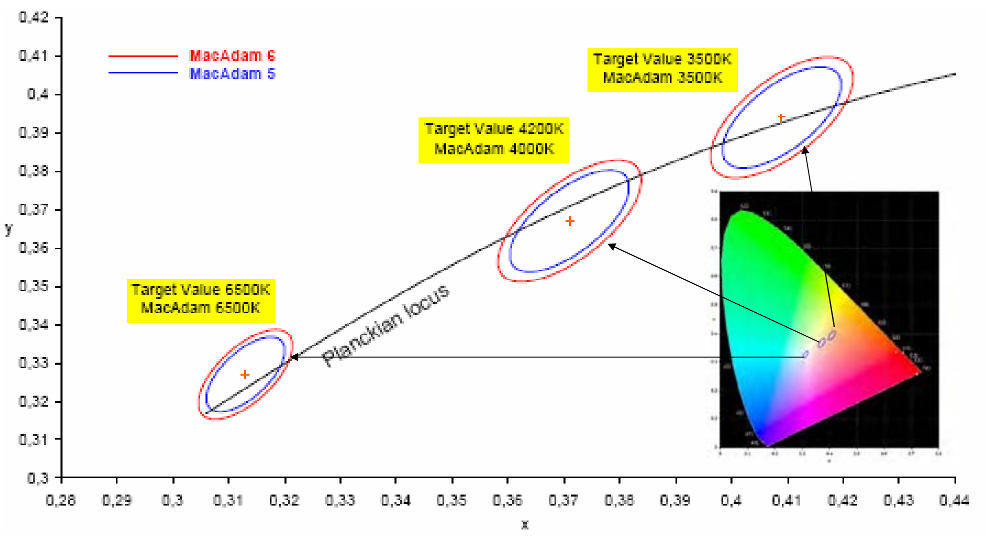
(Source: The Research Lighting Center)

Percentage of CFL eliminated



6 | Corporate Profile | 16/10/2007 | LEXEDIS

WHITE LIGHT QUALITY (ANSI Standard MacAdam-Ellipse 4)



7 | Corporate Profile 16/10/2007 LEXEDIS

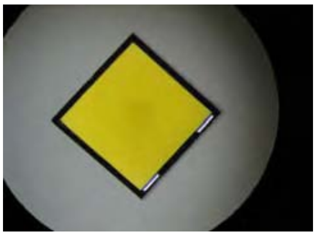
WHITE LIGHT QUALITY

TANGIBLE BENEFITS

- Exceeds Energy Star requirements
- White light reproducibility
- White light homogeneity
- Equal access to best quality light
- Procurement visibility
- Simple metric in line with existing standard

8 | Corporate Profile 16/10/2007 LEXEDIS

BEYOND THE PHOTON PROPOSITION



HIGH EFFICIENCY DIGITAL LIGHT SOURCE

- All Silicon (**Si**) miniature package
- 3D properties of Si for generic platform
- High precision and mould-free
- Lowest Thermal resistance (5K/W)
- Miniature form factor
- Integration of Added-Value functions

9 | Corporate Profile 16/10/2007 LEXEDIS

BEYOND THE PHOTON PROPOSITION

BUILT-IN ADDED-VALUE FUNCTIONS:

- Temperature sensor
- Photodiode
- ESD protection
- LED driver

10 | Corporate Profile 16/10/2007 LEXEDIS

XED PRODUCT RANGE: nanoXED

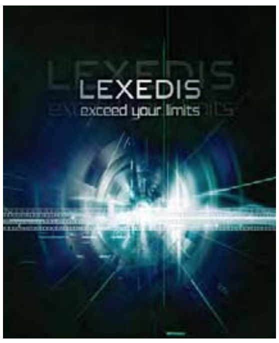
AVAILABLE

- **Size:** 2.5mm x2.5mm x0.6mm
- **Operating voltage**: 3.2V (typ.)
- **Operating current**: 200mA (typ.)
- **Luminous flux**: 35 lumen (200mA)
- **Rth:** 12K/W
- **Zero Colour Bin** → MacAdam Ellipse -6step
- **CCT**: 3000K, 3500K, 5500K, 6500K
- CRI: 85 ~ 90
- **Monochromatic colours**: Red, Green, Blue

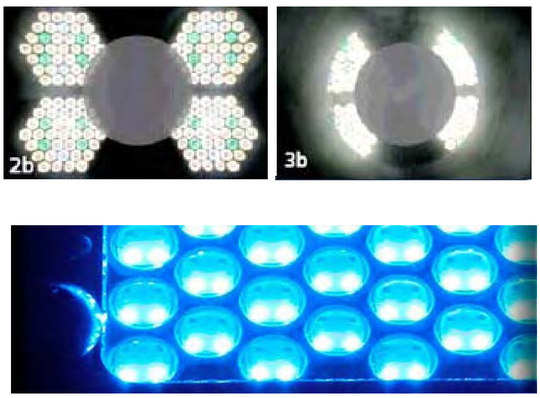
11 | Corporate Profile 16/10/2007 LEXEDIS

XED PRODUCT RANGE: powerXED

RELEASE: JUNE 2007



- **Size:** 2.5mm x2.5mm x0.6mm
- **Operating voltage**: 3.4V (typ.)
- **Operating current**: 350mA (typ.)
- **Luminous flux**: 55 lumen (350mA)
- **Rth:** 5K/W
- **Zero Colour Bin** → MacAdam Ellipse -6step
- **CCT**: 3000K, 3500K, 5500K, 6500K
- **CRI**: 85 ~ 90
- **Monochromatic colours:** Red, Green, Blue, Amber



12 | Corporate Profile 16/10/2007 LEXEDIS

XED VALUE PROPOSITION

• **SHIFTING FROM ''PHOTON VALUE'' TO ''INTELLIGENCE VALUE'' :**
→ Basic light emitter to smart Light processor

• **ENHANCE WHITE LIGHT QUALITY:**
→ Eliminate chromatic binning and aim for 4-step MacAdam

• **FOCUSING ON SUPERIOR QUALITY**:
→ Robust package architecture, indestructible optics, core-emitter resilience

• **SOLUTION SIMPLIFICATION:**
→ XED embedded in materials, driver integration, modular solutions

FOOD FOR THOUGHT

IN 1974 **BRAMBER PARISH COUNCIL** IN ENGLAND DECIDED TO GO WITHOUT STREET LIGHTING FOR THREE CONSECUTIVE DAYS AS A SAVING.

AFTERWARDS THE PARISH TRASURER WAS PLEASED TO ANNOUNCE THAT, AS A RESULT, ELECTRICITY TO THE VALUE OF **£ 11.59 HAD BEEN SAVED.**

HE ADDED , HOWEVER, THAT THERE WAS AN £18.48 BILL FOR SWITCHING THE ELECTRICITY OFF AND ANOTHER OF £12.00 FOR SWITCHING IT ON AGAIN.

IT HAD COST THE COUNCIL £18.89 TO SPEND THREE DAYS IN DARKNESS !

THANK YOU, GRAZZIE !

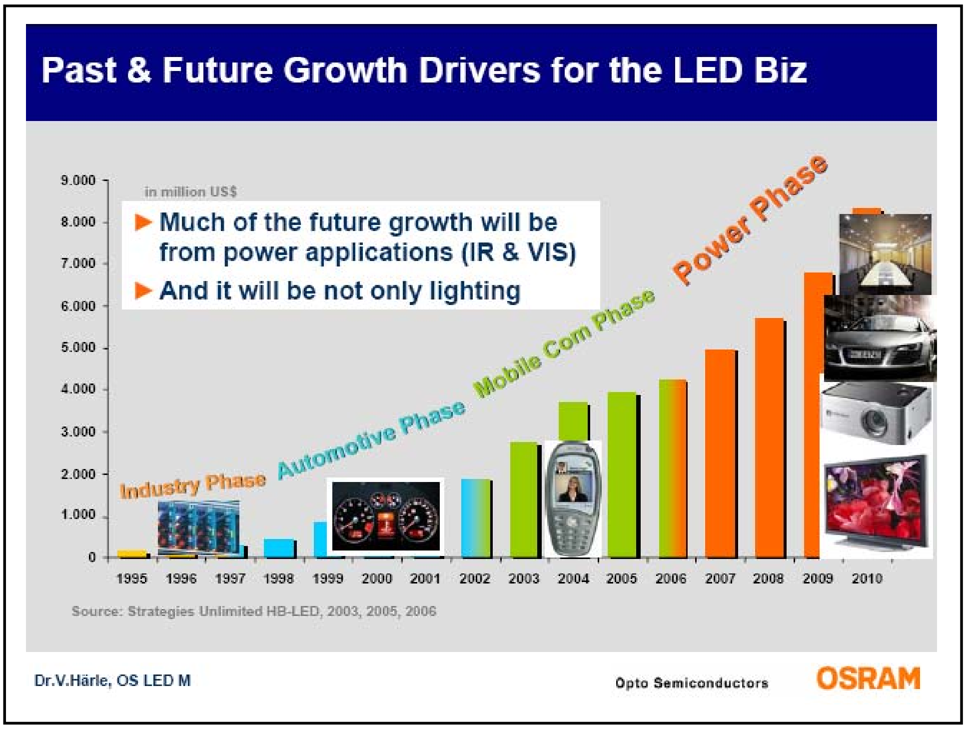
International Workshop on Status, Prospects and Strategies for LEDs in General Lighting

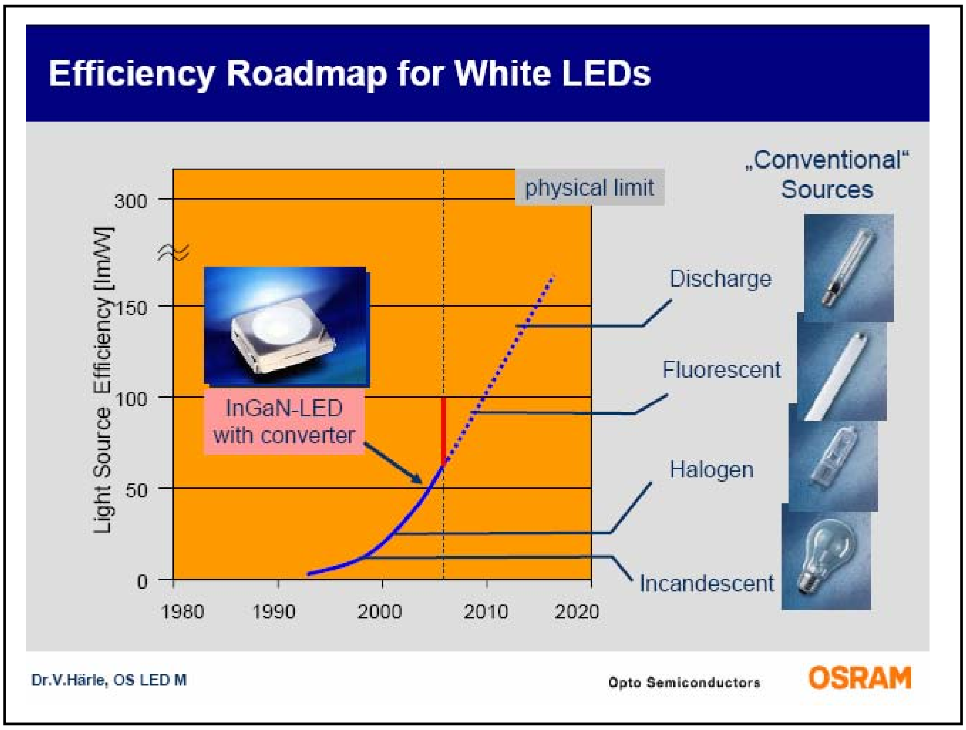
Dr.V.Härle, OS LED M — Opto Semiconductors OSRAM

Topics

1. Technology trends
2. LED Technology
3. High brightness LED market for GL

Dr.V.Härle, OS LED M — Opto Semiconductors OSRAM


Past & Future Growth Drivers for the LED Biz
in million US$
Much of the future growth will be from power applications (IR & VIS)
And it will be not only lighting
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0
Industry Phase
Automotive Phase
Mobile Com Phase
Power Phase
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Source: Strategies Unlimited HB-LED, 2003, 2005, 2006
Dr.V.Härle, OS LED M
Opto Semiconductors
OSRAM


Efficiency Roadmap for White LEDs
Light Source Efficiency [lm/W]
300
150
100
50
0
physical limit
InGaN-LED with converter
1980 1990 2000 2010 2020
„Conventional“ Sources
Discharge
Fluorescent
Halogen
Incandescent
Dr.V.Härle, OS LED M
Opto Semiconductors
OSRAM

LED in comparison to lamps

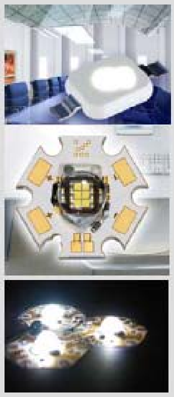
Power consumption:	**low**	**0.1W- 15 W**
A number of LEDs can be combined to form a powerfull source!		
Efficacy:	**high**	**30 - 60 lm/W**
Including optical efficiencies LEDs are equal or superior to most white light sources.		
Average life:	**high**	**10000 - 50000 h**
median life time is very high compared to conventional light sources.		

Dr.V.Härle, OS LED M

Opto Semiconductors

OSRAM

Additional LED advantages



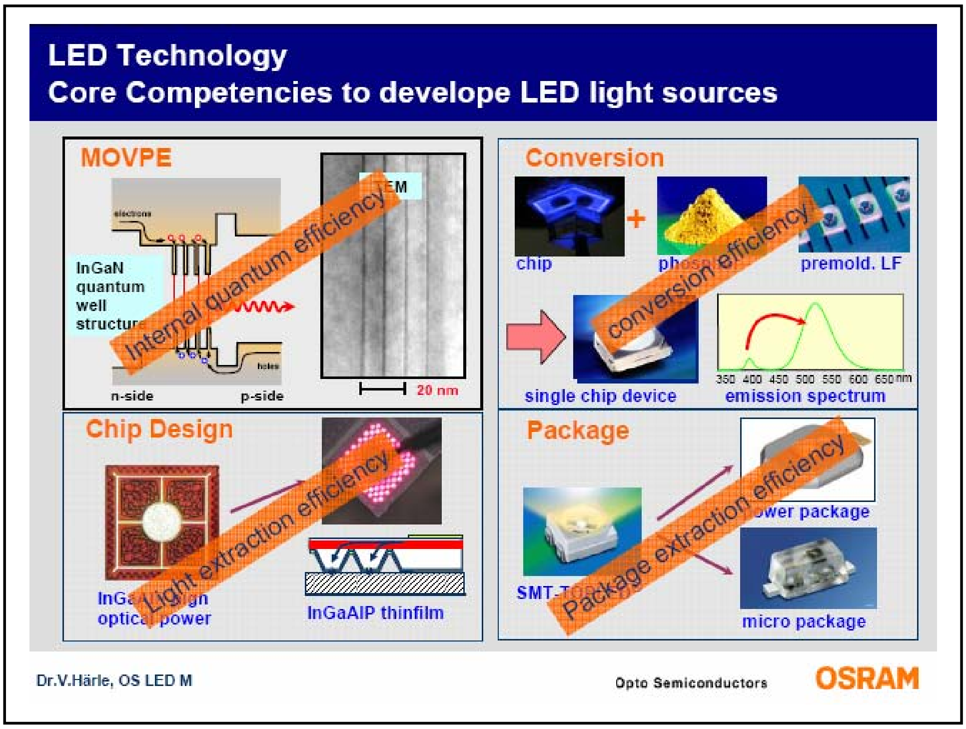
- Point light source
  ⇒ Possibility to direct the light
- Pre-shaped light (candela output)
- Size of the light source
- Color rendering
- full dimming possible
- Color variability
- Color saturation
- Maintenance cost during a fixed luminaire life

⇒ There are many questions to be considered
For many applications, LEDs are the right and innovative choice!

Dr.V.Härle, OS LED M

Opto Semiconductors

OSRAM


LED Technology
Core Competencies to develope LED light sources
MOVPE
InGaN quantum well structure
n-side
p-side
20 nm
Internal quantum efficiency
Conversion
chip
premold. LF
single chip device
emission spectrum
conversion efficiency
Chip Design
InGaAlP thinfilm
Light extraction efficiency
Package
micro package
Package extraction efficiency
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Opto Semiconductors
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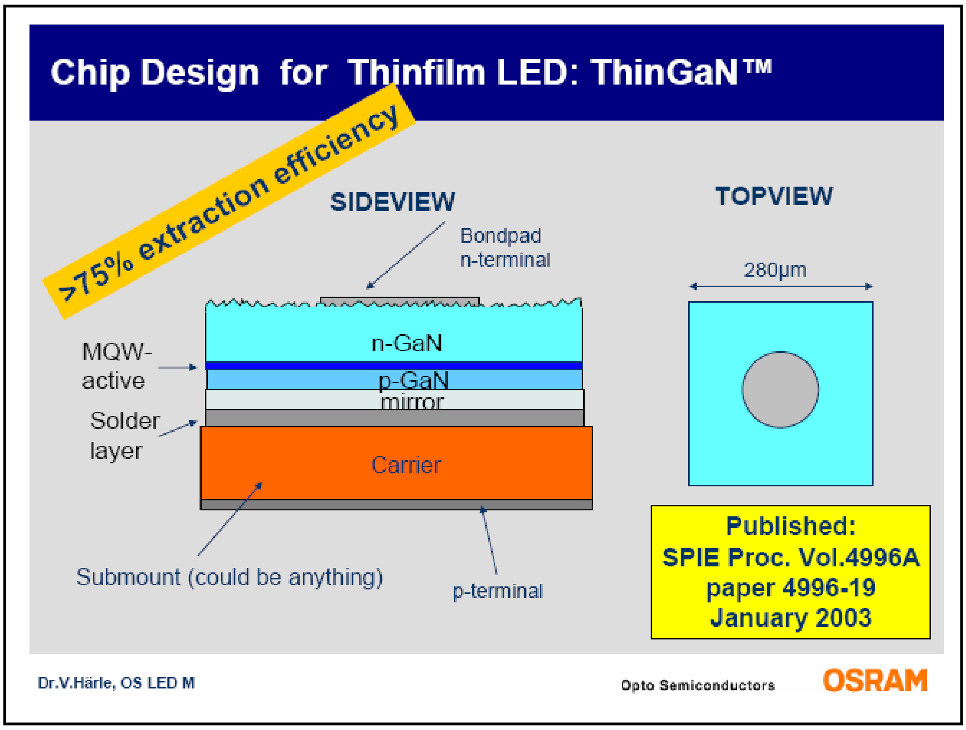
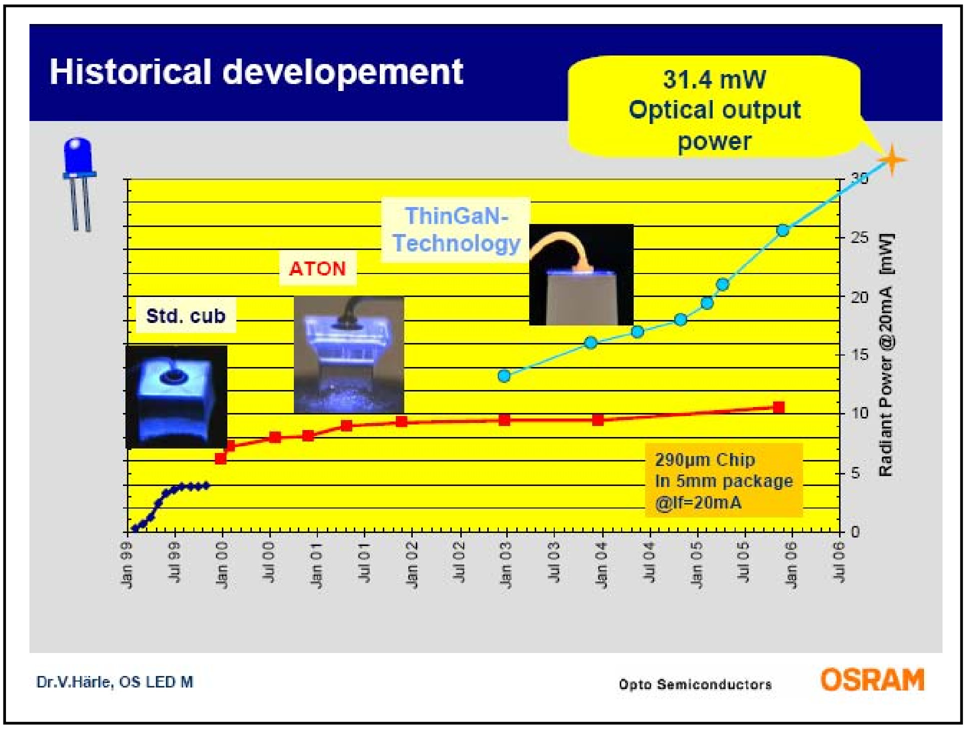
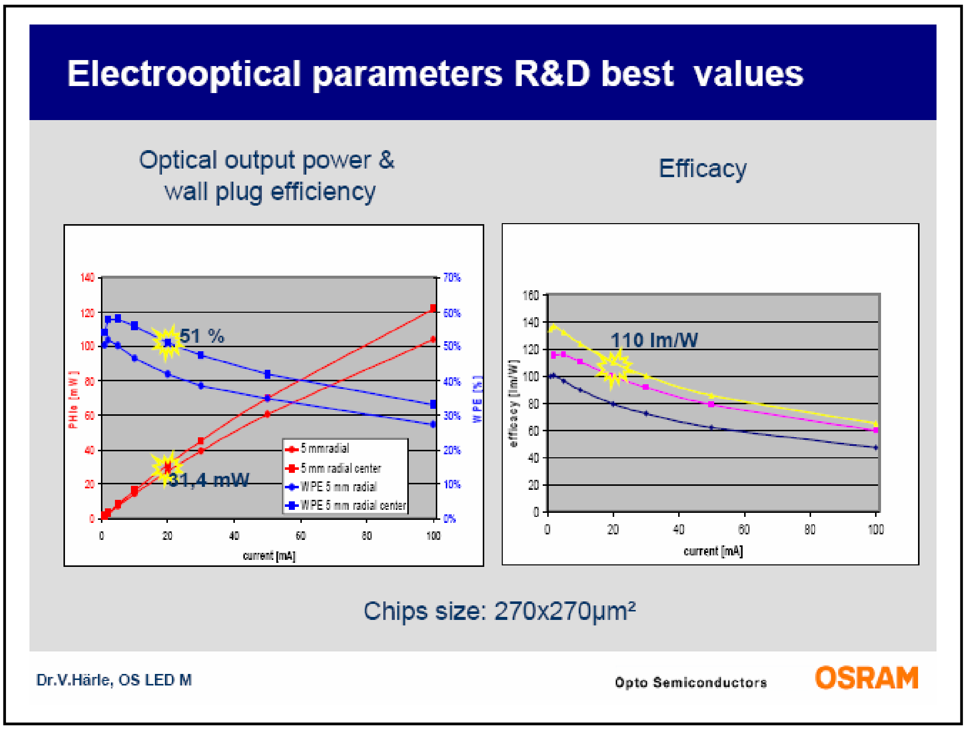

Chip Design for Thinfilm LED: ThinGaN™
>75% extraction efficiency
SIDEVIEW
TOPVIEW
Bondpad
n-terminal
280µm
MQW-
active
Solder
layer
n-GaN
p-GaN
mirror
Carrier
Submount (could be anything)
p-terminal
Published:
SPIE Proc. Vol.4996A
paper 4996-19
January 2003
Dr.V.Härle, OS LED M
Opto Semiconductors
OSRAM


Historical developement
31.4 mW
Optical output
power
ThinGaN-
Technology
ATON
Std. cub
290µm Chip
In 5mm package
@If=20mA
Radiant Power @20mA [mW]
0
5
10
15
20
25
30
Jan 99
Jul 99
Jan 00
Jul 00
Jan 01
Jul 01
Jan 02
Jul 02
Jan 03
Jul 03
Jan 04
Jul 04
Jan 05
Jul 05
Jan 06
Jul 06
Dr.V.Härle, OS LED M
Opto Semiconductors
OSRAM


Electrooptical parameters R&D best values
Optical output power &
wall plug efficiency
Efficacy
51 %
31,4 mW
5 mmradial
5 mm radial center
WPE 5 mm radial
WPE 5 mm radial center
current [mA]
110 lm/W
efficacy [lm/W]
current [mA]
Chips size: 270x270µm²
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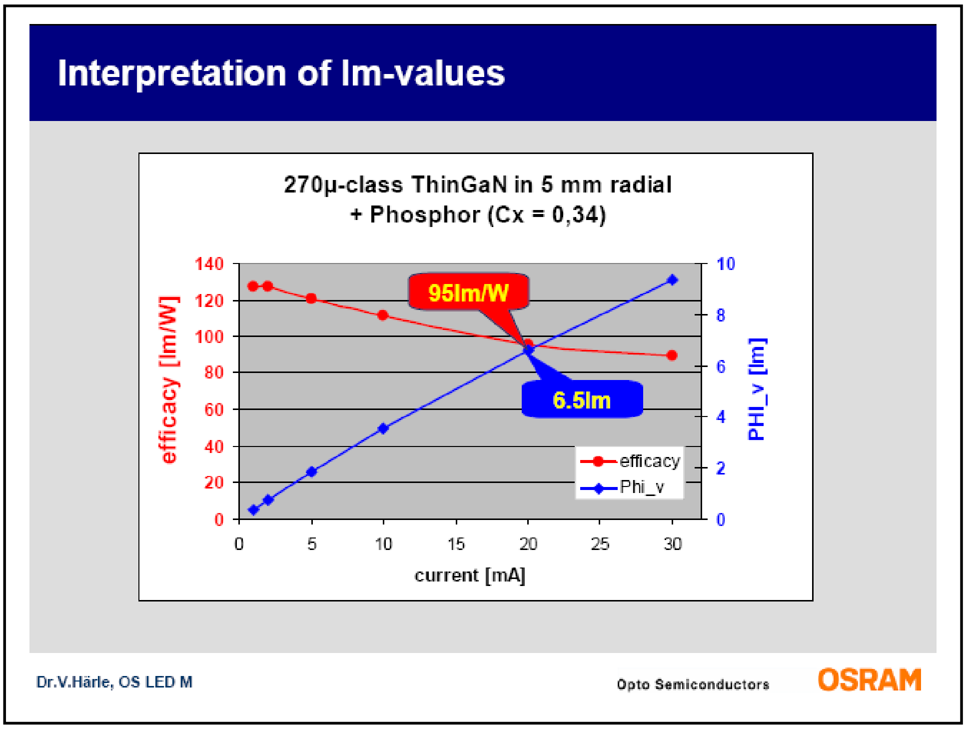
Interpretation of lm-values
270µ-class ThinGaN in 5 mm radial
+ Phosphor (Cx = 0,34)
95lm/W
6.5lm
efficacy [lm/W]
PHI_v [lm]
current [mA]
efficacy
Phi_v
0
20
40
60
80
100
120
140
0
2
4
6
8
10
0
5
10
15
20
25
30
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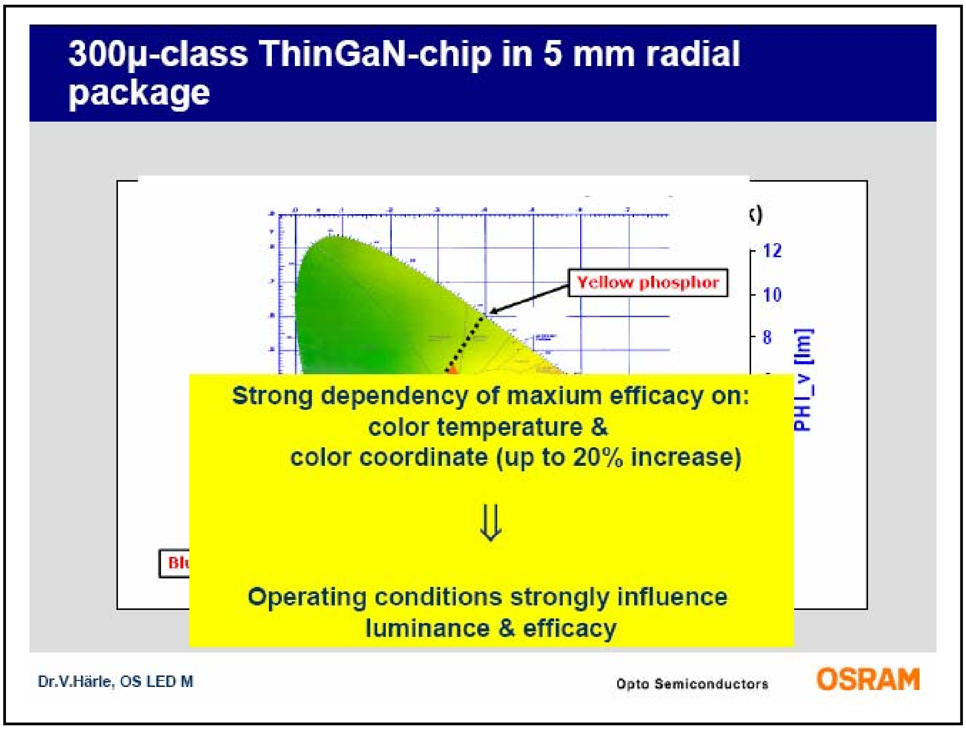
300µ-class ThinGaN-chip in 5 mm radial package
Yellow phosphor
12
10
8
PHI_v [lm]
Strong dependency of maxium efficacy on:
color temperature &
color coordinate (up to 20% increase)
⇓
Operating conditions strongly influence
luminance & efficacy
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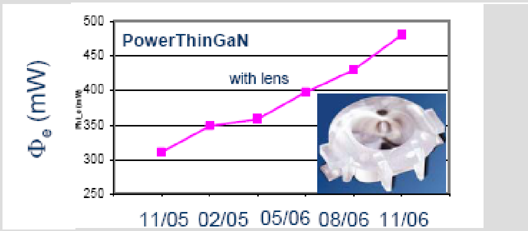
Evolution of PowerThinGaN R&D achievements: optical power / efficiencies

R&D values achieved:



⇒ **R&D values increased by 54% since 11/05**

Status of typical efficiency splitting

	Internal Quantum Efficiency (IQE)	Light Extraction Eff. (LEE)
PowerThinGaN:	72% (@350mA)	75%

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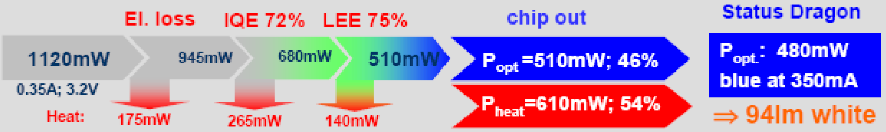
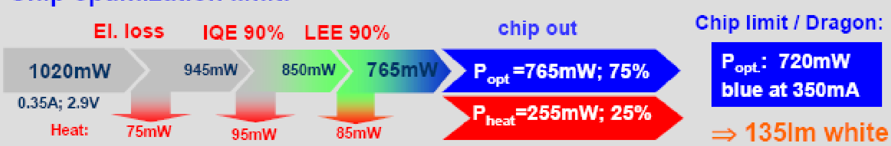
Electrical and optical power flow; Chip optimization limit

Status today:



- IQE 72% (Powerchip) and LEE 75% leads to 480mW blue & 94lm white

Chip optimization limit:



⇒ **Limit for 1mm chip e.g. in Dragon w. lens at 135-150lm (350mA)**

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On the move to 1000 lm white

More lumens ⇒ increasing current !

1st approach: Constant chip size
⇒ increase current density

2nd approach: Constant current density
⇒ increase chip size

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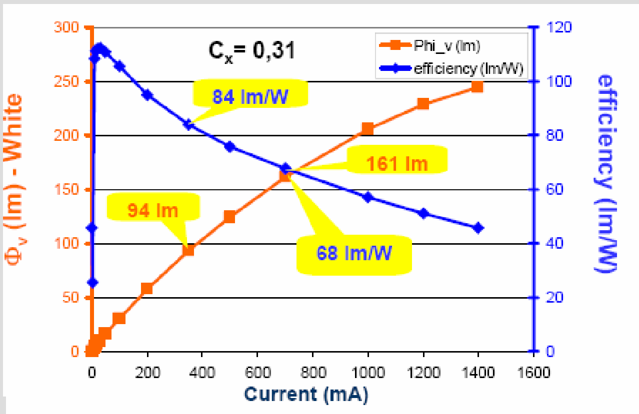
R&D – White: Brightness



lm output saturates with increasing current

⇒ efficiency drops significantly at high currents

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Limitation for high current operation

Power flow at increased currents

350mA:	1000mA:	1400mA:
$P_{electr.}$=1.12W	$P_{electr.}$=3.75W	$P_{electr.}$=5.6W
P_{opt}=425mW; 38%	P_{opt}=884mW; 24%	P_{opt}=1.07W; 19%
P_{heat}=695mW; 62%	P_{heat}=2.87W; 76%	P_{heat}=4.53W; 81%

⇒ Heat management becomes extremely important at high current

Improved thermal conductivity: Chip
Carrier
Package
Fixture

⇒ ΔR_{th} of 7K/W yields ≈5% Φ_e increase and ≈ 20K T_j decrease at 1A

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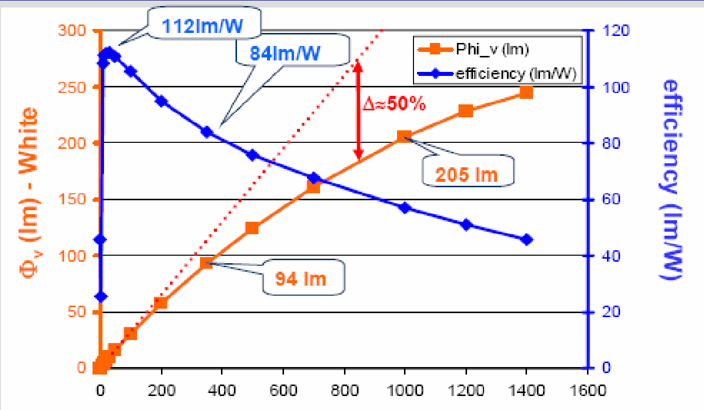
Non-linearity is key issue at high currents



Im output saturates & efficiency drops with increased current

⇒ non-linearity is a key issue for efficient high current operation

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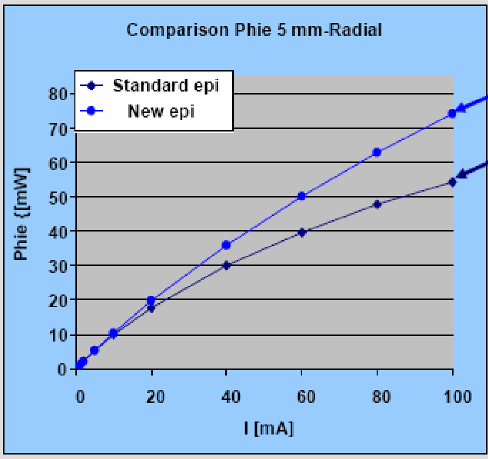
Comparison linearity status: old process – new process



New epi: λ_{peak}=447 nm
Linearity 80/20=3,15

Standard epi: λ_{peak}=451 nm
Linearity 80/20=2,7

Enhancement of linearity 80/20 from 2,7 to 3,15 in the blue region with introduction of new epi

Brightness increase: 25% @ 60mA

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On the move to 1000 lm white

More lumens by increased current !

1st approach: Constant chip area

- Efficiency drops at increased current
- Heat management extremely important at high currents
- Non-linearity is key issue for efficient high current operation

2nd approach: Constant current density

$\Rightarrow$ increase chip area

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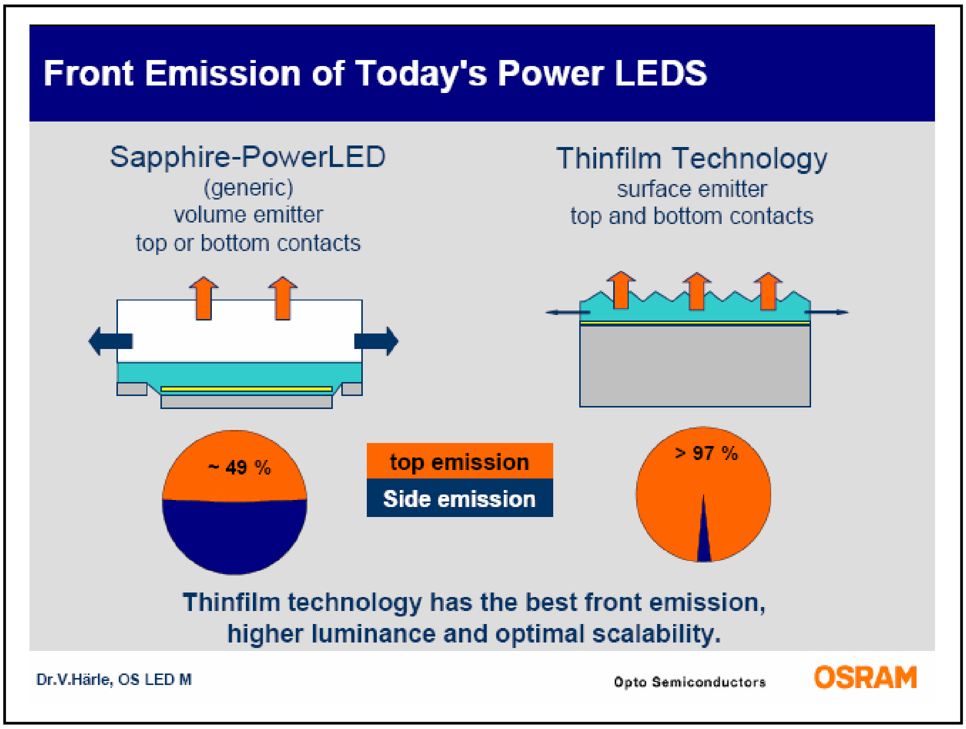
Front Emission of Today's Power LEDS
Sapphire-PowerLED
(generic)
volume emitter
top or bottom contacts
Thinfilm Technology
surface emitter
top and bottom contacts
~ 49 %
top emission
Side emission
> 97 %
Thinfilm technology has the best front emission, higher luminance and optimal scalability.
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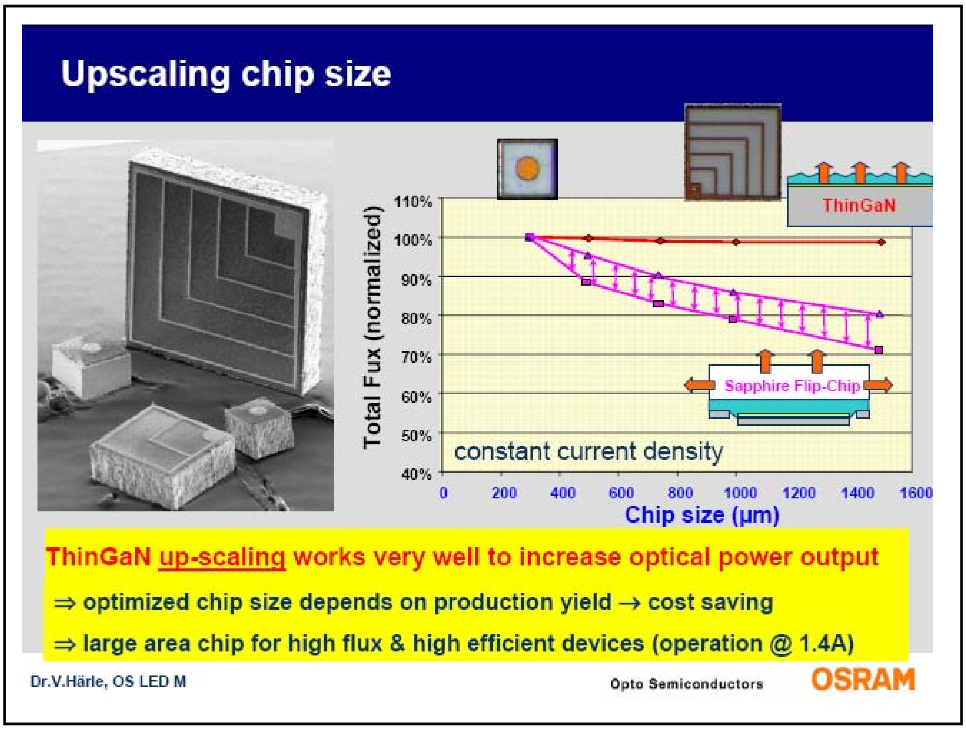
Upscaling chip size
ThinGaN
Total Fux (normalized)
110%
100%
90%
80%
70%
60%
50%
40%
Sapphire Flip-Chip
constant current density
0
200
400
600
800
1000
1200
1400
1600
Chip size (µm)
ThinGaN up-scaling works very well to increase optical power output
⇒ optimized chip size depends on production yield → cost saving
⇒ large area chip for high flux & high efficient devices (operation @ 1.4A)
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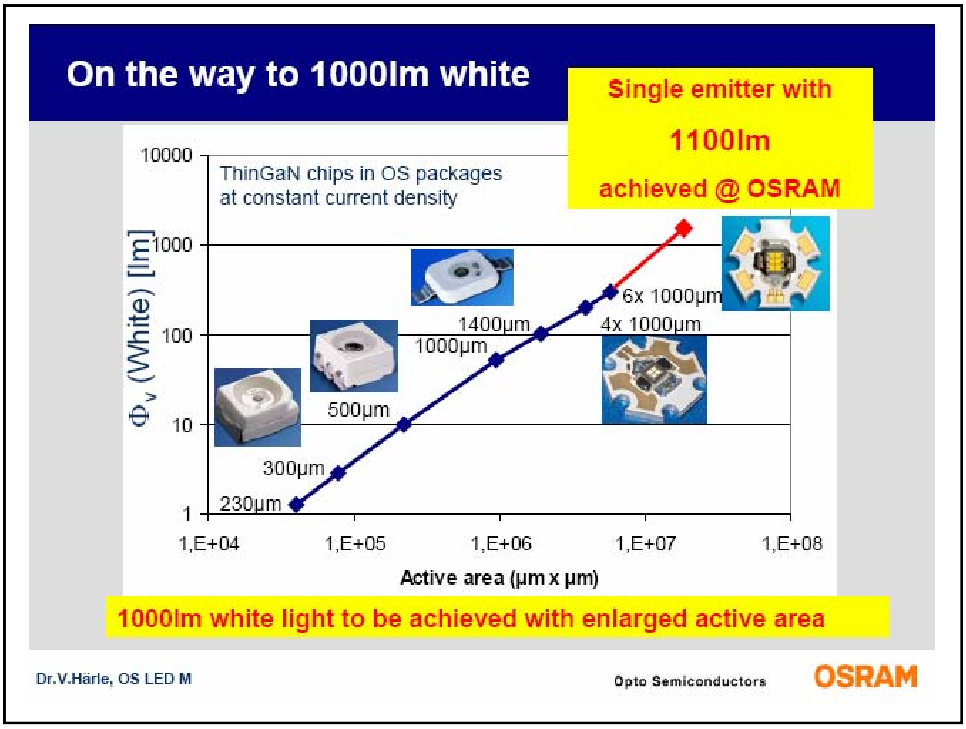

On the move to 1000 lm white

More lumens by increased current !

1st approach: Constant chip size ⇒ increase current density

- **Efficiency drops at increased current**
- **Heat management very important at high currents**
- **Linearity is key issue for efficient high current operation**

2nd approach: Constant current density ⇒ increase chip size

- **ThinGaN proves scaleability ⇒ most efficient appoach**
- **optimum chip size limited by other factors**
  e.g. production yield

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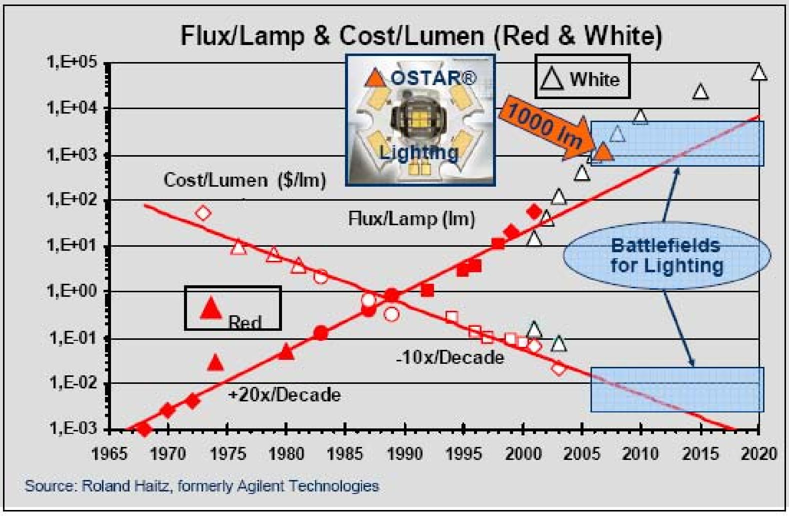
Cost and performance developments



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Summary

- PowerThinGaN: Chip-Technology of choice for LEDs
- Chip improvement demonstrated
  →R&D values increased by 54% since 11/05
- Outlook on IQE and LEE limits luminance performance
  → limit for Dragon at 135-150lm → higher current needed for 1000lm
- Increased luminance by increased driving current
  → Efficiency drops at increased current
  → Heat management very important at high currents
  → Linearity is key issue for efficient high current operation
  →Chip size limited by additional factors e.g. production yield

⇒ 1100lm demonstrated for GL

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Semiconductor Light for lighting
General Lighting
Wellness Lighting
2010
30 - 70 lm/W
Corporate Lighting
2005
Architectural lighting
Marker Light
2003
15 - 40 lm/W
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Focus market segments for active market development
1 Architec-tural
• Building facades
• Wall wash
• Flood lights
• Cove lighting
• Landscape l.
2 Retail display
• Display case lighting
• General merchandize lighting
• Refrigerators
3 Consumer portable
• Flashlights
• Headlights
• Bicycle lights
(especially in Asia)
4 Channel letters
• Channel letters
• Contour lighting, e.g gas stations
5 Resi-dential
• Decorative
• Under cabinet
• Pendants
• Reading lights
6 Outdoor
• Parking lots
• Pedestrian areas
• Street lighting
• Public places
Strong market segmentation, dominated by Archtectual Lighting
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Past and Present – main application

Visualisation

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Past and Present – main application

Decoration / City Beatification

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Past and Present – main application

Effect-lighting

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Past and Present – main application

Cove Lighting

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Additional Indoor Lighting

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Past and Present – main application

Illumination

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Past and Present – main application

Illumination

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Past and Present – main application

Facade-Lighting

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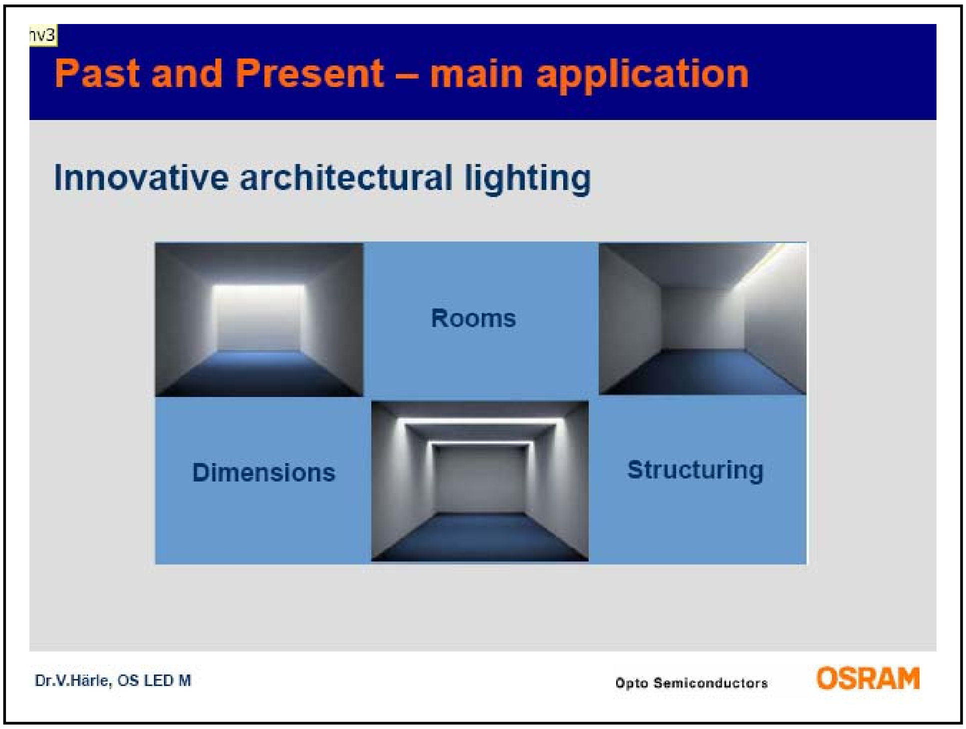
hv3
Past and Present – main application
Innovative architectural lighting
Rooms
Dimensions
Structuring
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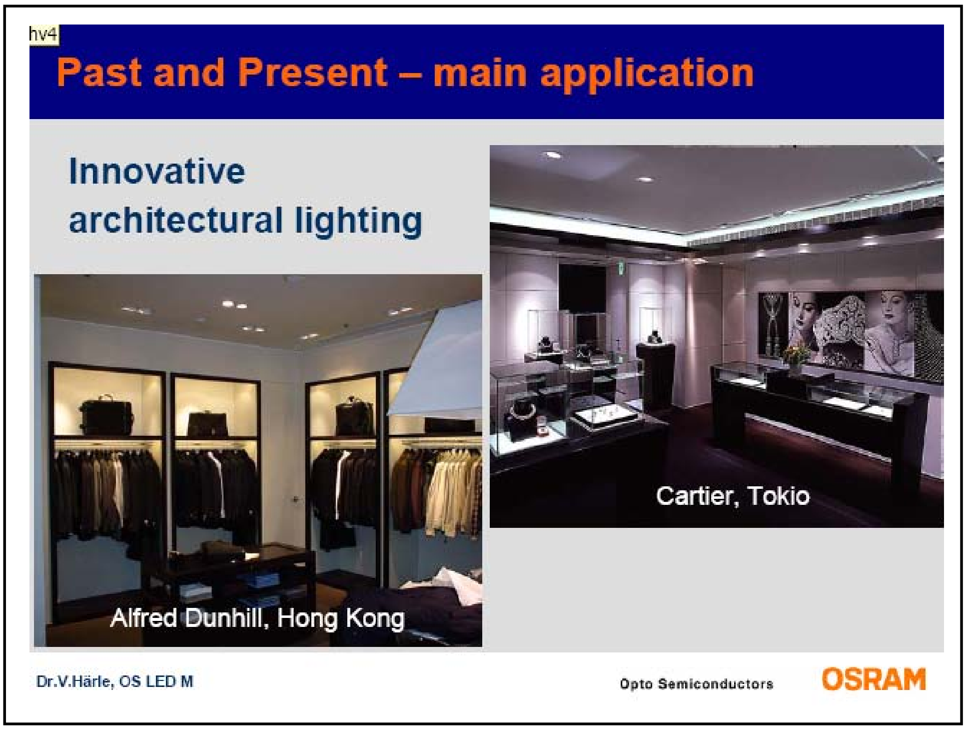
hv4
Past and Present – main application
Innovative
architectural lighting
Cartier, Tokio
Alfred Dunhill, Hong Kong
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Opto Semiconductors
OSRAM


Thank you!

Enabling the Solid State Lighting Revolution

Giuliano Cassatatro
Sales Director
Solid State Lighting
Giuliano_Cassatatro@cree.com

CREE

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CREE LED Light

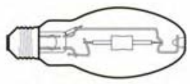
 pg. 2

Incumbent Lighting Sources

Incandescent

Pros: Very cheap, great color
Cons: Very short lifetime, poor energy efficiency

High Intensity Discharge



Pros: Cheap, efficient
Cons: Poor color, long restart, short lifetime

Fluorescent

Pros: Cheap, energy efficient
Cons: Can not run in cold temp; difficult/costly to dim, control

Compact Fluorescent

Pros: Energy efficient
Cons: Poor color quality, Can not run in cold, High cost vs. Incand

Halogen

Pros: Great color, focused light
Cons: Very short lifetime, poor energy efficiency

 pg. 3

CREE LED Light

Incumbent Lighting Technologies vs. SSL

- Every incumbent lighting technology has at least one major disadvantage → That is why there are so many of them!
- LEDs:
  - Have very **long lifetime** → >50,000 hours to 70% LM
  - Are very **energy efficient** → >80LPW
  - Are inherently **rugged** → No filament to break
  - **Start instantly** → nanoseconds vs. > 10 min (HID)
  - Are **directional** → No wasted light, any pattern possible
  - Are **environmentally sound** → no Hg, Pb, heavy metals
  - Are **infinitely dimmable, controllable** → New lighting features, power savings
  - Love cold temperatures → **No cold starting issues**
- ...But...LEDs are currently **disadvantaged in COST** relative to **some** incumbent technologies and applications

 pg. 4

CREE LED Light

Moving the Performance Bar Enables New Apps…

- SSL started over two decades ago as indicator lights, novelties, and toys
- Traffic signals were next…
- Then Automotive (driven by RED)…
- Then Cell phones…
- Then architectural (RGB)…
- Then torch lights (white)…
- Now, Outdoor…
- *Next*, Indoor & Industrial…

Technically, SSL can replace nearly all incumbent applications…

 pg. 5

CREE LED Light

Four Strategies for Enabling SSL

- **Fix cost problem**
  - Perhaps the easiest to fix…
  - Semiconductors ALWAYS get cheaper with volume…
- **Keep pushing energy efficiency boundaries**
  - Need to EXTEND LPW advantages well beyond incumbent lighting technologies to create compelling reason to switch
- **Exploit other advantages of SSL**
  - Directionality
  - Long Lifetime / Maintenance
  - Regulatory (no Hazardous materials)
- **Education and industry re-organization**
  - Huge opportunity for those who are quick and recognize this potential

 pg. 6

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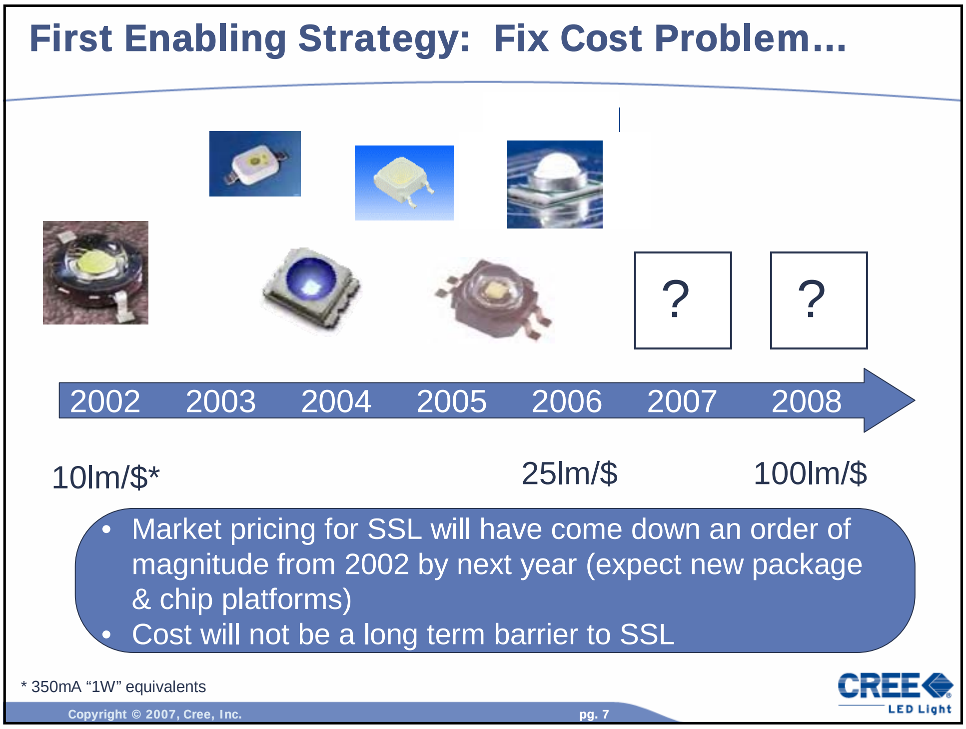
First Enabling Strategy: Fix Cost Problem…
?
?
2002
2003
2004
2005
2006
2007
2008
10lm/$*
25lm/$
100lm/$
• Market pricing for SSL will have come down an order of magnitude from 2002 by next year (expect new package & chip platforms)
• Cost will not be a long term barrier to SSL
* 350mA "1W" equivalents
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pg. 7
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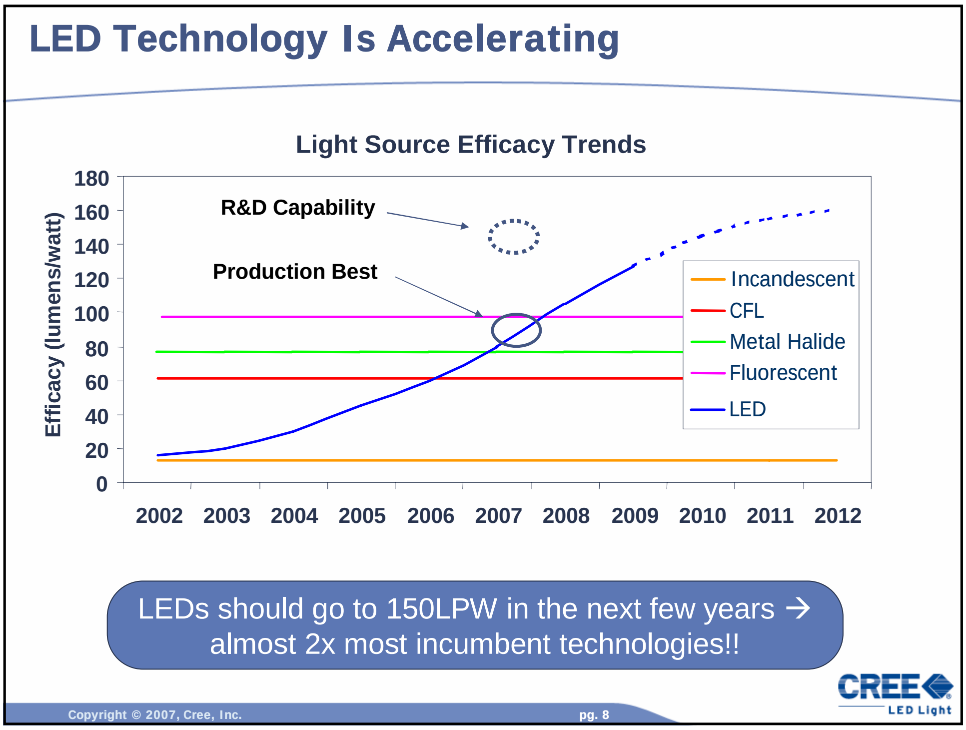
LED Technology Is Accelerating
Light Source Efficacy Trends
Efficacy (lumens/watt)
180
160
140
120
100
80
60
40
20
0
R&D Capability
Production Best
Incandescent
CFL
Metal Halide
Fluorescent
LED
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
LEDs should go to 150LPW in the next few years → almost 2x most incumbent technologies!!
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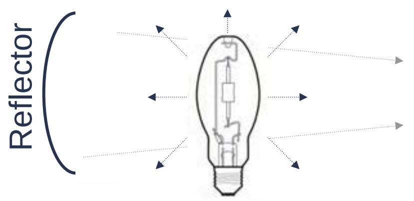
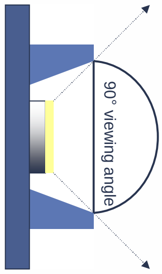
Third Strategy: Exploit Inherent SSL Advantages

Conventional Lighting



XLamp LED



- Conventional lighting is inherently omni-directional
  - Can be re-directed into useful light with reflectors (with high losses)
- LED Light is inherently directional
- Secondary optics are available to further focus light

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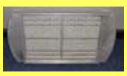
Directionality Makes Fixtures More Efficient

Luminaire Type		Lumens Per Watt	Fixture Efficiency	Usable Lumens Per Watt
Incandescent		13	70%	9
Compact Fluorescent		61	36%	22
Metal Halide Streetlight (150W)		86	50%	43
Industrial Metal Halide (400W)		71	61%	43
LED Concept Fixture (400W Metal Halide)		72	78%	58
4x T5 Fluorescent Troffer		107	77%	82

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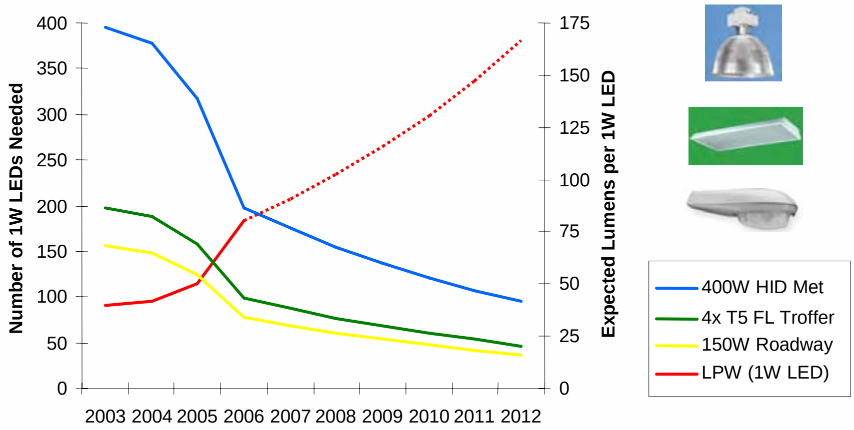
Tipping Point is Close On All The Major Apps…



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Energy Savings & Maintenance Avoidance Makes the Value Proposition Work

Either Way: Total system reliability (> 50,000 hours) is a critical requirement…

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Early Examples: Outdoor LED Luminaires

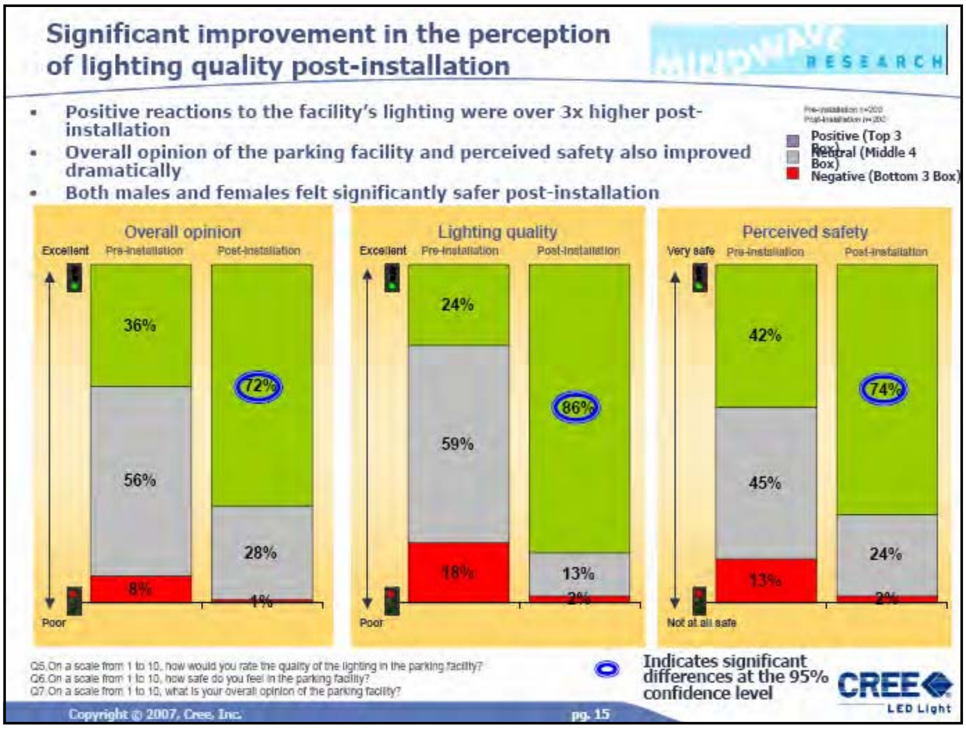
 pg. 13 CREE LED Light

Real Economic Value Created – NOW

- Commercially available LEDs
- Commercially available fixtures
- Delivering >40% total power savings – as measured by the Power Company

- Plus: Where would you rather walk at night…?

 pg. 14 CREE LED Light


Significant improvement in the perception of lighting quality post-installation
Positive reactions to the facility's lighting were over 3x higher post-installation
Overall opinion of the parking facility and perceived safety also improved dramatically
Both males and females felt significantly safer post-installation
Positive (Top 3 Box)
Neutral (Middle 4 Box)
Negative (Bottom 3 Box)
Overall opinion
Excellent
Pre-installation
Post-installation
36%
56%
8%
72%
28%
1%
Poor
Lighting quality
24%
59%
18%
86%
13%
2%
Perceived safety
Very safe
42%
45%
13%
74%
24%
2%
Not at all safe
Indicates significant differences at the 95% confidence level
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Another LED Deployment – Guangzhou China
MULTI-CELL
Solar-powered street lights
Guangzhou Multi-Cell Semiconductor Lighting Technology Co., LTD
Will new players like Multi-cell lead the way…?
CREE LED Light
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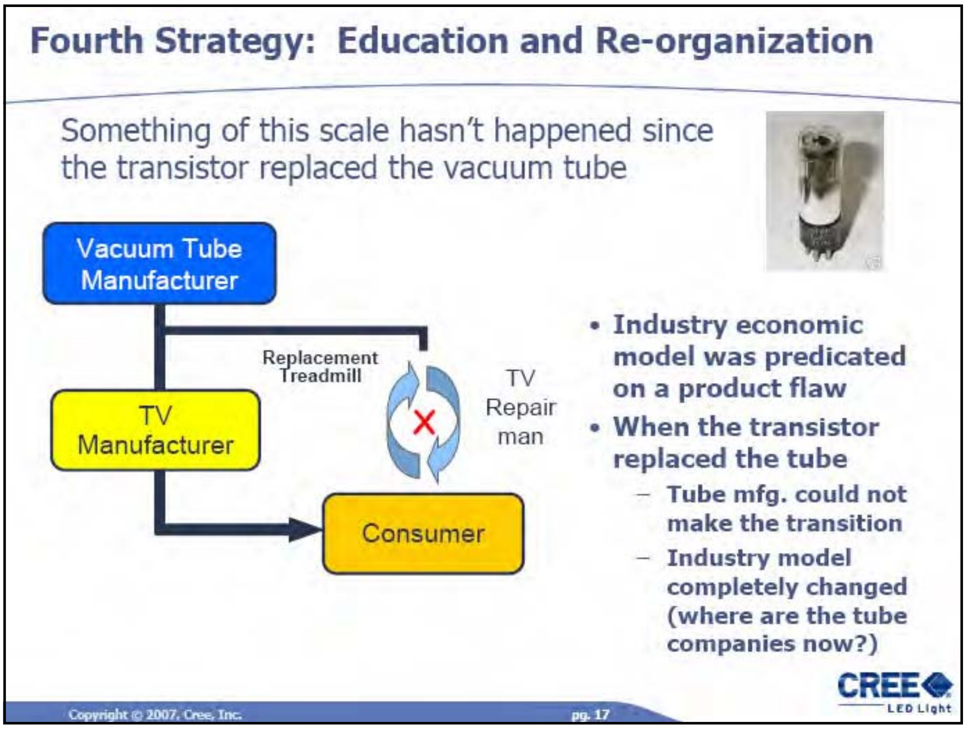
pg. 16


Fourth Strategy: Education and Re-organization
Something of this scale hasn't happened since the transistor replaced the vacuum tube
Vacuum Tube Manufacturer
TV Manufacturer
Replacement Treadmill
TV Repair man
Consumer
• Industry economic model was predicated on a product flaw
• When the transistor replaced the tube
– Tube mfg. could not make the transition
– Industry model completely changed (where are the tube companies now?)
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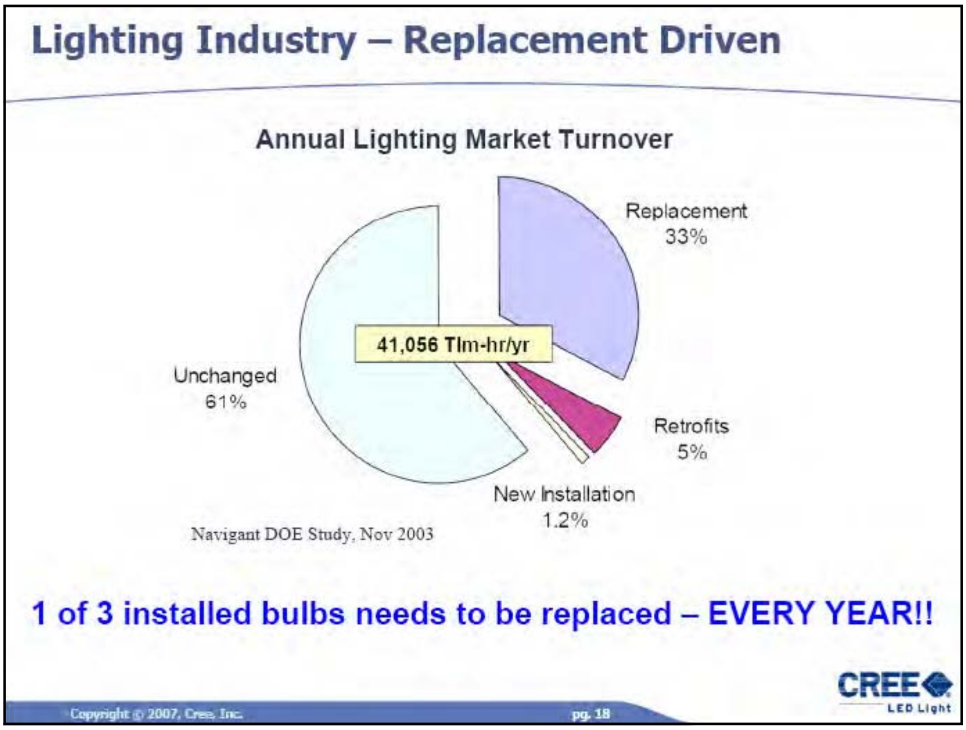
CREE
LED Light


Lighting Industry – Replacement Driven
Annual Lighting Market Turnover
Replacement 33%
41,056 Tlm-hr/yr
Unchanged 61%
Retrofits 5%
New Installation 1.2%
Navigant DOE Study, Nov 2003
1 of 3 installed bulbs needs to be replaced – EVERY YEAR!!
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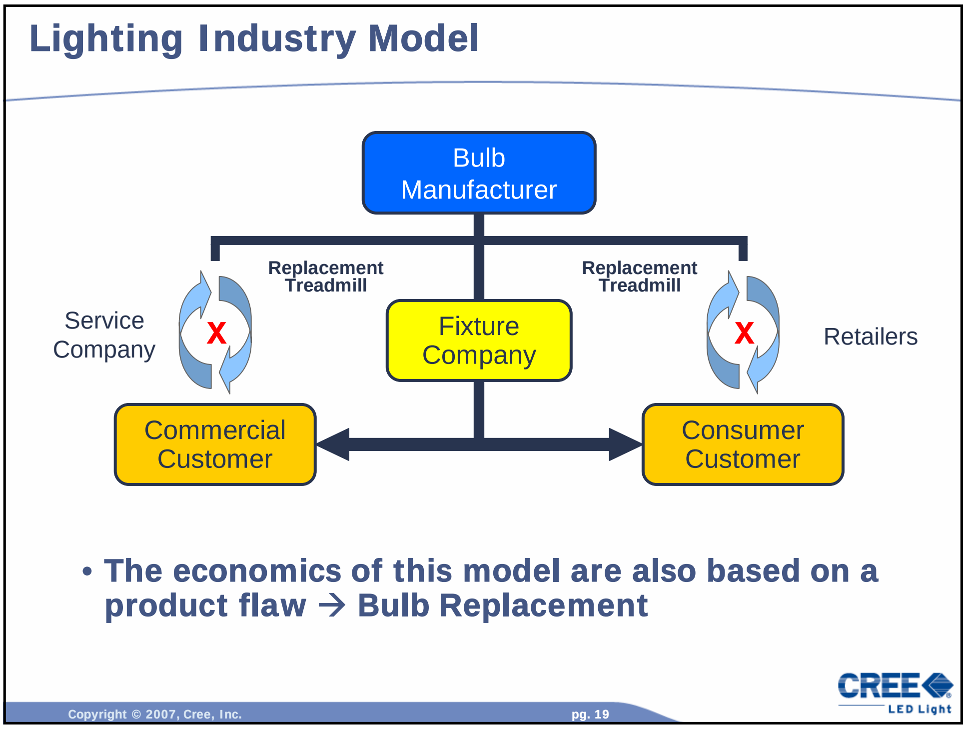
CREE
LED Light


Lighting Industry Model
Bulb Manufacturer
Replacement Treadmill
Replacement Treadmill
Service Company
X
Fixture Company
X
Retailers
Commercial Customer
Consumer Customer
• The economics of this model are also based on a product flaw → Bulb Replacement
CREE LED Light
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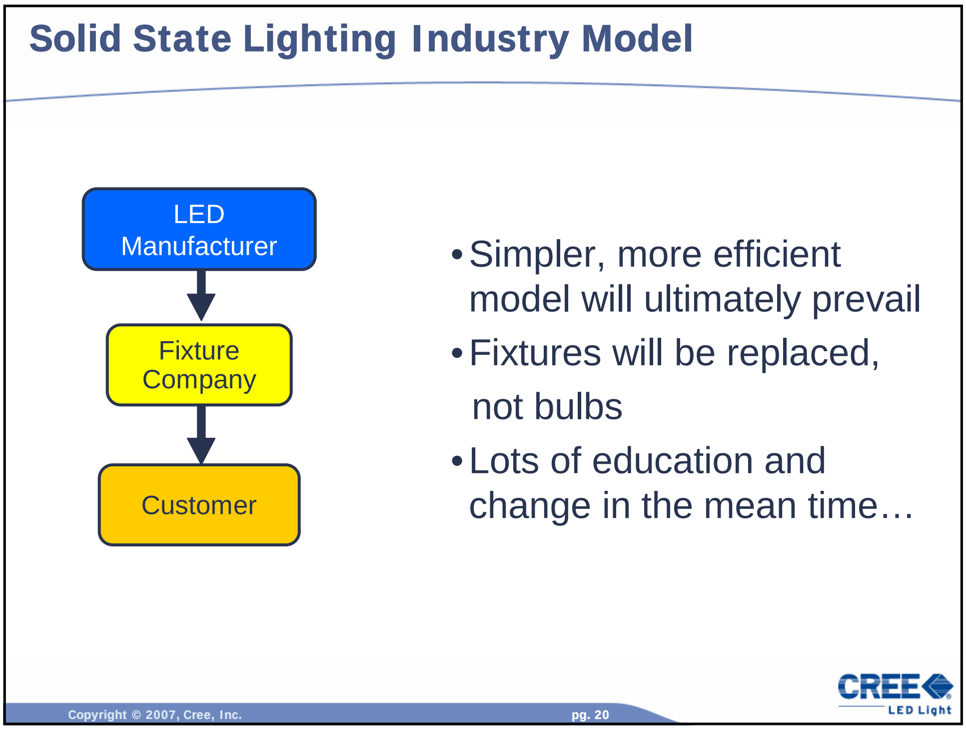
pg. 19


Solid State Lighting Industry Model
LED Manufacturer
Fixture Company
Customer
• Simpler, more efficient model will ultimately prevail
• Fixtures will be replaced, not bulbs
• Lots of education and change in the mean time…
CREE LED Light
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Summary

- **Incumbent lighting technologies are decades old and the industry economics are dependent on a flaw in the product (bulb replacement)**
- **LEDs can *Technically* replace almost any incumbent technology, but falls short for some applications today on cost**
- **Enabling SSL will take time and focus on**
  - **Fixing the short-term LED cost problem (relatively easy)**
  - **Extending LED energy savings (LPW) advantage to create compelling switching motivation (also inevitable)**
  - **Exploiting maintenance, directionality, and regulatory advantages of LEDs (a harder job)**
  - **Education and industry re-organization to take full economic advantage of this paradigm change (a longer proposition)**

 pg. 21

PHILIPS

Recent Advances in Power LED Technology and Expectations for the Future

Umberto Dusi
International Workshop on Status, Prospects and Strategies for LEDs in General Lighting
03, May 2007

LUMILEDS
LIGHT FROM SILICON VALLEY

PHILIPS

LUMILEDS

Outline

I. Philips Lumileds Mission

II. Recent Advances and objectives in LED Technology
   1. Thin Film devices
   2. Solving the “droop” problem
   3. Phosphors
   4. Packaging

III. Outlook for Illumination

Philips Lumileds, Umberto Dusi, May 3, 2007 2

Philips Lumileds Mission

Sustained Technology Supremacy in Power LEDs

Enabling

Never Before Possible Lighting Solutions

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Sustained Technology Supremacy Requires Development of:

1. High Efficacy Power Chip Architectures
2. High Efficacy, High Power Epi Structures
3. Tight Color Control
4. Ultra Small, Low Cost Power Packaging

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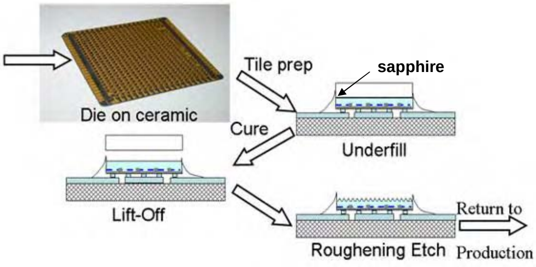
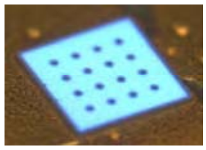
1. Thin Film Flip Chip

Improved Extraction Efficiency





Removal of sapphire substrate results in a 50% gain in White performance and a 30% gain in Blue and Green.

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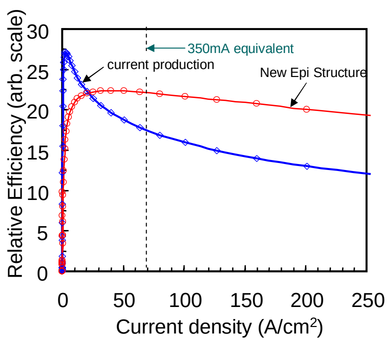
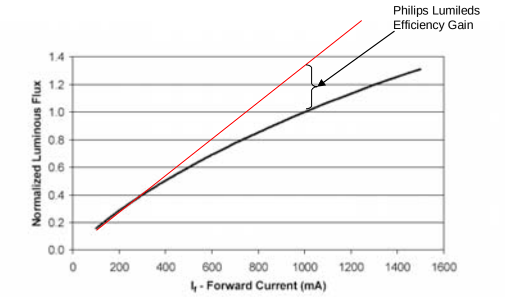
2. High efficiency at high currents

Efficiency droop with current





New Epi structure produces a 30% gain at 1A drive with very little efficiency loss.

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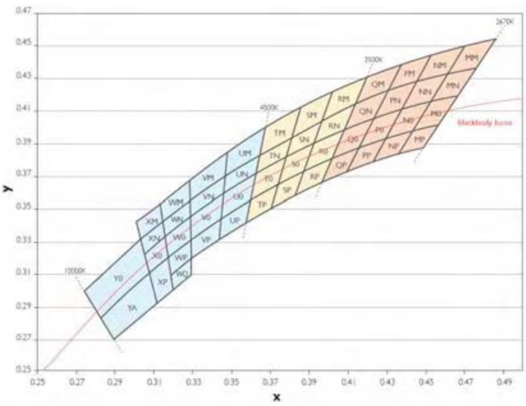
3. Philips Lumileds White Color Control Technology

white color binning with introduction of warm-white, neutral-white and cool-white colors

Finer bin structures and selection

Objectives for illumination grade color control

- High CCT consistency (+/-50 CCT @ 3000K)
- Deliver the same bin, on the Black Body Curve every time
- Need higher performance "warm" white with good CRI for general illumination



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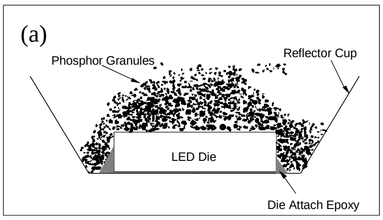
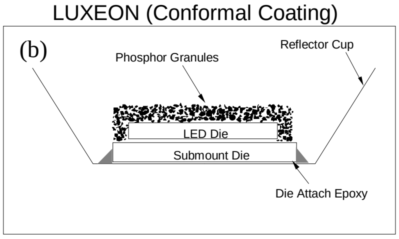
3. White Light Quality and Color Temperature

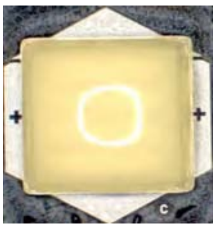
Conventional



LUXEON (Conformal Coating)



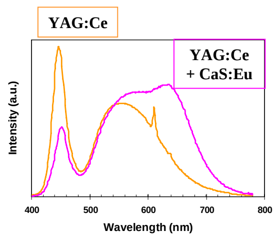
Free standing white chip



Improved Uniformity

	YAG:Ce	YAG:Ce + CaS:Eu	
CRI:	**~75**	**~90**	
CCT:	**~6000**	**~3200K**	
Conv. Eff.:	**~200**	**~160 lm/W$_{opt}$**	

- Excellent match to blackbody radiation.
- Need higher performance "warm" white with good CRI for general illumination.



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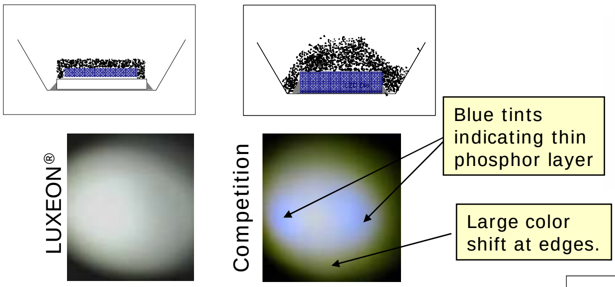
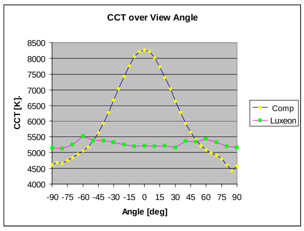
3. Tight Color Control
Conformal Phosphor (Available Today)



Actual Results

- Patented conformal phosphor process for LUXEON provides <500K color variation
- Other LEDs: >3500K color variation over the viewing angle



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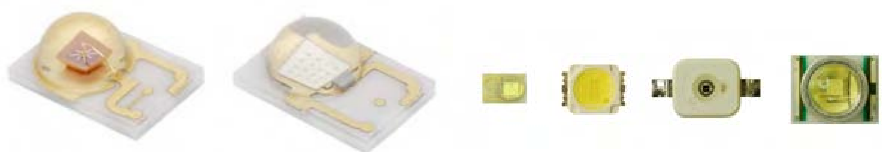
4. Ultra Small, Low Cost Power Packaging
LUXEON Rebel Platform



Performance:
- Size: 3x4.5mm vs. 7.2 x 7.2mm
- Light output, efficiency, reliability leader in 350mA – 1A class
- Packing density: Up to 6x other power LEDs
- Lowest cost/improved Lumens/$
- Outperforms Chip-on-Board (performance, reliability)
- improved color mixing and diffusing
- smaller luminaire design

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The outlook for illumination

1. Where do LEDs stand compared to conventional technology (lm/W)
2. The evolution of LED brightness (Meganits)
3. The outlook for performance

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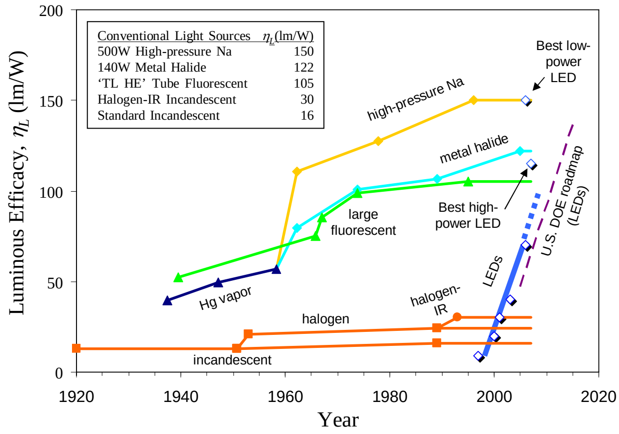
White light source luminous efficacy: conventional vs. LEDs



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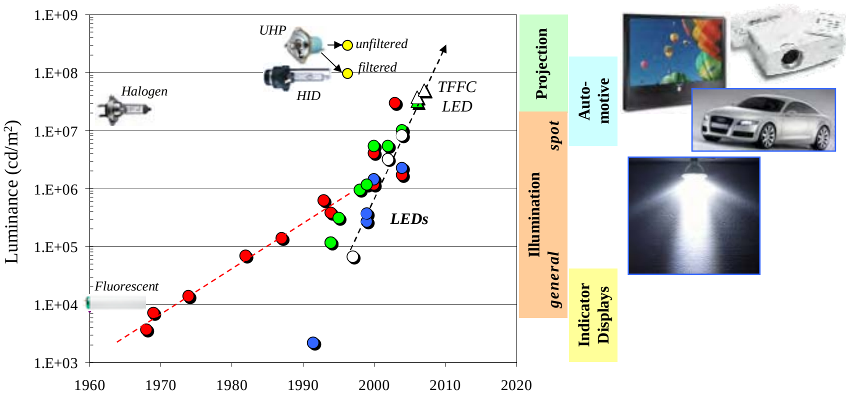
InGaN Devices: Evolution of LED source brightness



- 50 M cd/m^2 (“Meganits”) measured at 1 A drive current

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150 lm/W is within sight

Using next-generation device technology, Philips Lumileds set a new world record for efficiency in a white power LED - breaking the 100 lm/W barrier for the first time from a single 1*1 mm^2 chip:

Philips Lumileds High-Power, White LED		
Current	350 mA	2000 mA
Lumens	136	502
Lumens per Watt	115	61
Watts	1.2	8.3

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Summary

- Power LEDs are improving rapidly and continued improvement is expected. Performance of 100 lm/W will happen soon and ~150 lm/W is likely.
- As efficacy increases, thermal management is simplified and system costs can be reduced.
- Key areas for future improvement are white uniformity, CCT and CRI.
- It is now clear that LEDs also should dominate general illumination. Full conversion at 150 lm/W would “save” over 100 nuclear reactors worldwide.

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Session 3

Chair: Kalle Hashmi, Swedish Energy Agency, Sweden

International Workshop on Status, Prospects and Strategies for LEDs in General Lighting

- ORGANISED BY:
- THE EUROPEAN COMMISSION
- DIRECTORATE-GENERAL JRC
- JOINT RESEARCH CENTRE
- Institute for Environment and Sustainability
- Renewable Energies Unit

  - Ispra, Italy – 3 & 4 May 2007

  - KALLE HASHMI
  - SWEDISH ENERGY AGENCY

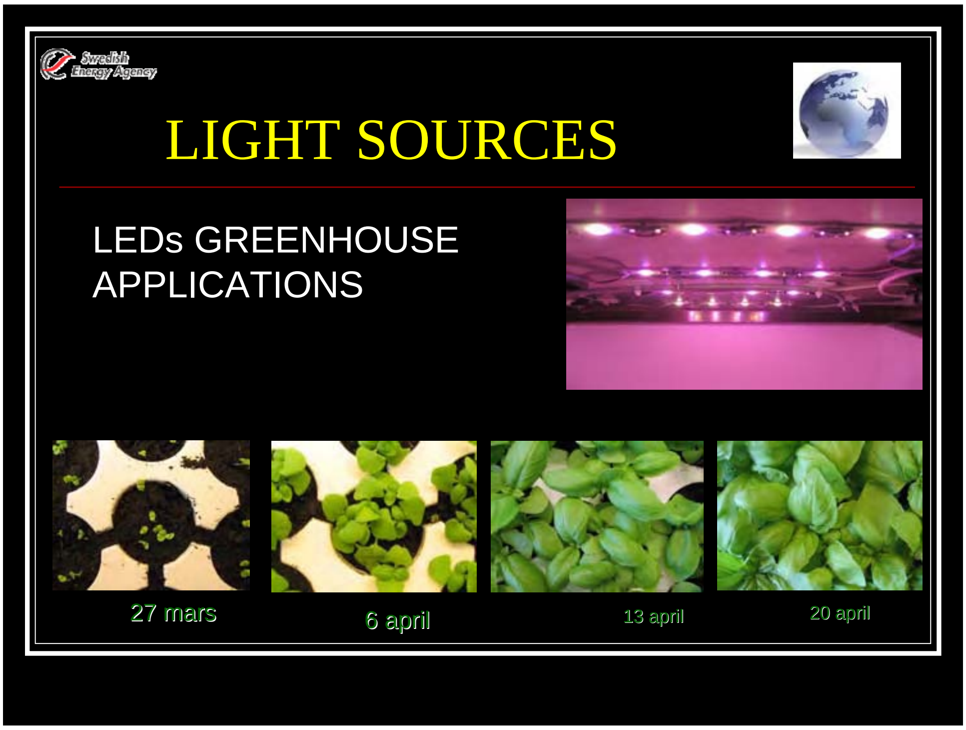
LIGHT SOURCES

A BRIGHTER IDEA

LIGHT EMITTING DIODE
last much longer
much less space
extremely energy-efficient
contain no mercury
Digital (internet controllable)


Swedish Energy Agency
LIGHT SOURCES
LED BASED TRAFFIC SIGNALS
100 WATT INCANDESCENT TO
< 20 WATT LED


Swedish Energy Agency
LIGHT SOURCES
LED BASED EXIT SIGNS
> 11WATT
TO
< 1WATT


Swedish Energy Agency
LIGHT SOURCES
LEDs GREENHOUSE
APPLICATIONS
27 mars
6 april
13 april
20 april

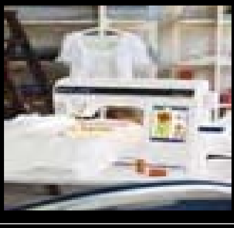

Swedish Energy Agency
LIGHT SOURCES
ARCHITECTURAL LIGHTING

LIGHT SOURCES

LED BASED SIGNAGE

LIGHT SOURCES

- SEWING MACHINES

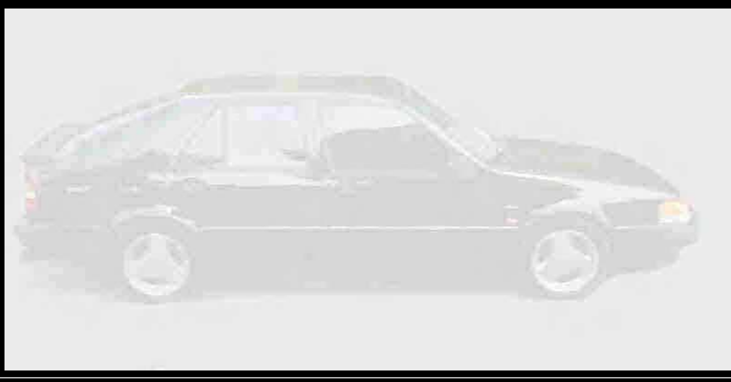


LIGHT SOURCES

- LED LIGHTING IN TRAIN TOALETT

LIGHT SOURCES

- SAAB INTERIOR LIGHTING



Swedish Energy Agency

LIGHT SOURCES

LED IN COMMERCIAL FREEZERS

Swedish Energy Agency

LIGHT SOURCES

- LED- BASED ELEVATOR LIGHTING

Swedish Energy Agency

SWEDISH ZINK OXIDE RESEARCH

- CHEAPER MATERIAL THAN GALLIUM NITRIDE
- CHEAP SUBTRATE MATERIAL; CAN BE GROWN ON PLASTIC. DOES NOT REQUIRE THE SAME ATOMIC STRUCTURE IN SUBTRATE AND THE LIGHT GENERATING MATERIAL
- QUANTUM EFFICIENCY IS 100% VIS-A-VIS 50% FOR GALLIUMNITRIDE
- LOW HEAT GENERATION
- SIMPLE MANUFACTURING TECHNOLOGY e.g. 50^0 C, NO VACCUME OR CLEAN ROOM ENVIRONMENTS REQUIRED

Swedish Energy Agency

SWEDISH WHITE LED TECHNOLOGY ADVANTAGES

- *LUMINOUS EFFICACY* (POTENTIAL) 200 LUMEN/WATT
- *LIFETIME* > (POTENTIAL) 100 000 HOURS
- *COST/1000 LUMEN* < (POTENTIAL) U.S. $ 1 (ONE)
- *WHITE LIGHT QUALITY (CONTINUOUS SPECTRUM)*

illumina

avra illuminato?

illuminava

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Tense Lighting: Past, Present, Future Perfect?

Patricia Rizzo, MSc

Status, Prospects and Strategies for LEDs in General Lighting

Ispra, Italy

May 5, 2007

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The Year Is...

- 1879
  - Incandescent bursts onto scene
  - Transforms housing infrastructure
- 1917
  - 20% homes electrified
- 1940
  - 90% homes electrified

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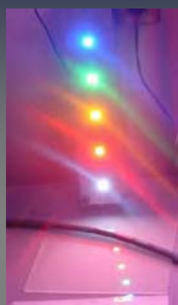
The Year Is...

- 2007
  - Technology has made incredible advancements
  - We are so far from the first carbon filament lamp

    ...or are we?

  - 87% of lamps in residences are still incandescent



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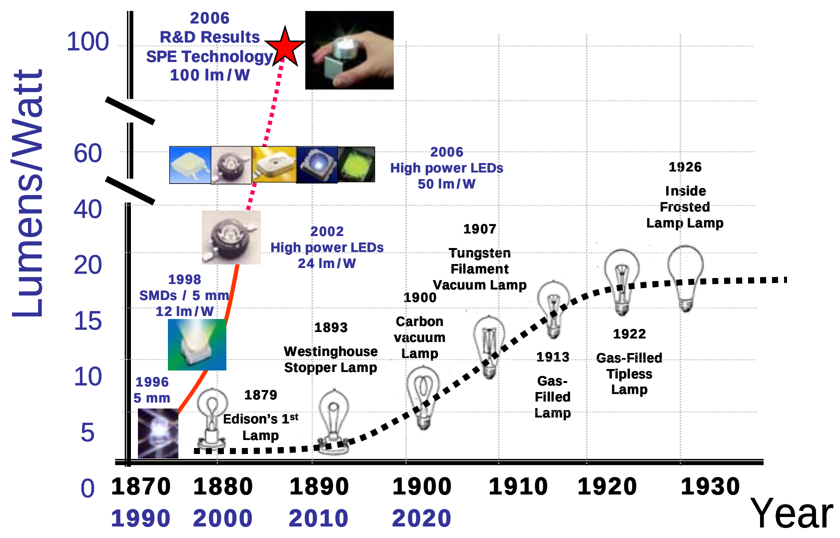

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Present

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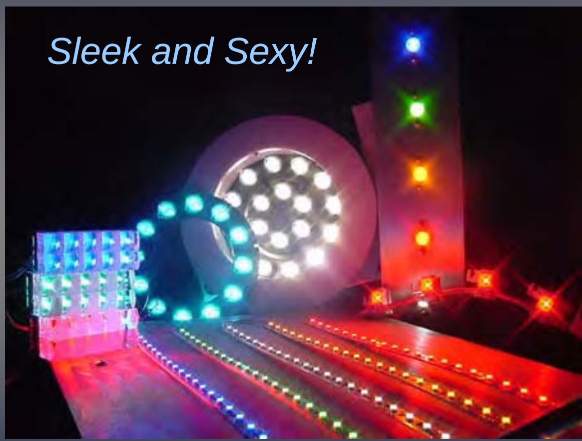
LEDs – an 'Able' Technology

Adaptable

Durable

Controllable

Flexible



Long life

Programmable

Sustainable

Tunable

Affordable?

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Transmit Information

Crosswalk

Roadway Delineation

Tunnel

Intersection

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Universal Design.....is a framework for the design of places, things, information, communication and policy to be usable by the widest range of people operating in the widest range of situations *without special or separate design*. Most simply, Universal Design is human-centered design of everything with everyone in mind.

http://www.adaptenv.org/

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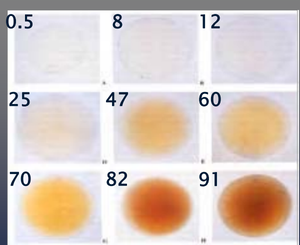
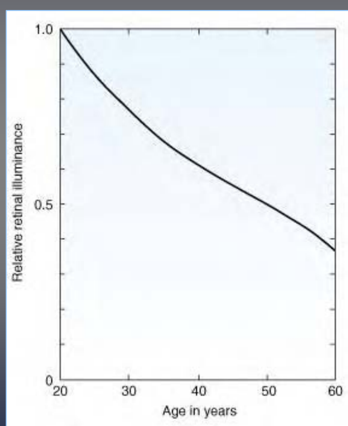
Optical Changes to Visual System

- Age-related optical changes (before age 65)
  - Smaller pupil size
  - Thicker, yellower crystalline lens

Yellowing of lens (by age)





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Loss of Contrast

Age Related Loss of Retinal Illuminance and Contrast

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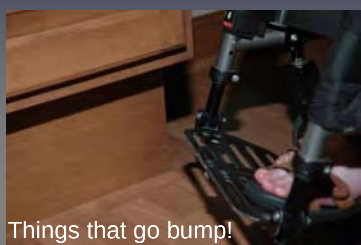
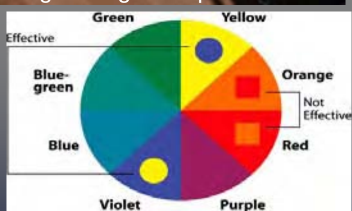
Provide Contrast





http://www.lighthouse.org/color_contrast.htm

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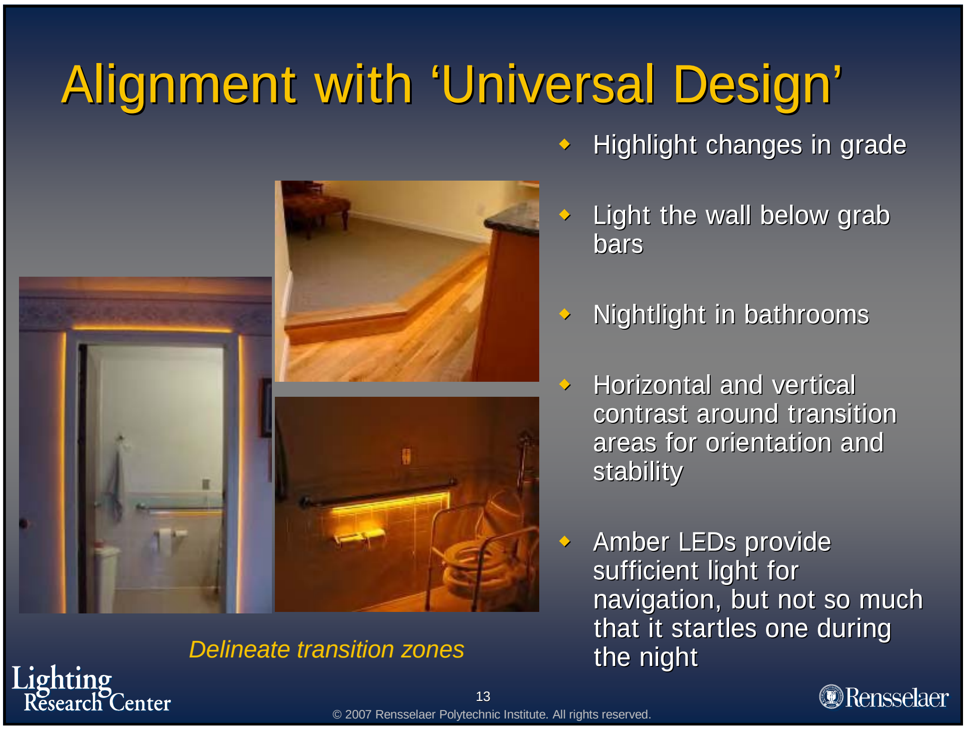
Alignment with 'Universal Design'
Highlight changes in grade
Light the wall below grab bars
Nightlight in bathrooms
Horizontal and vertical contrast around transition areas for orientation and stability
Amber LEDs provide sufficient light for navigation, but not so much that it startles one during the night
Delineate transition zones
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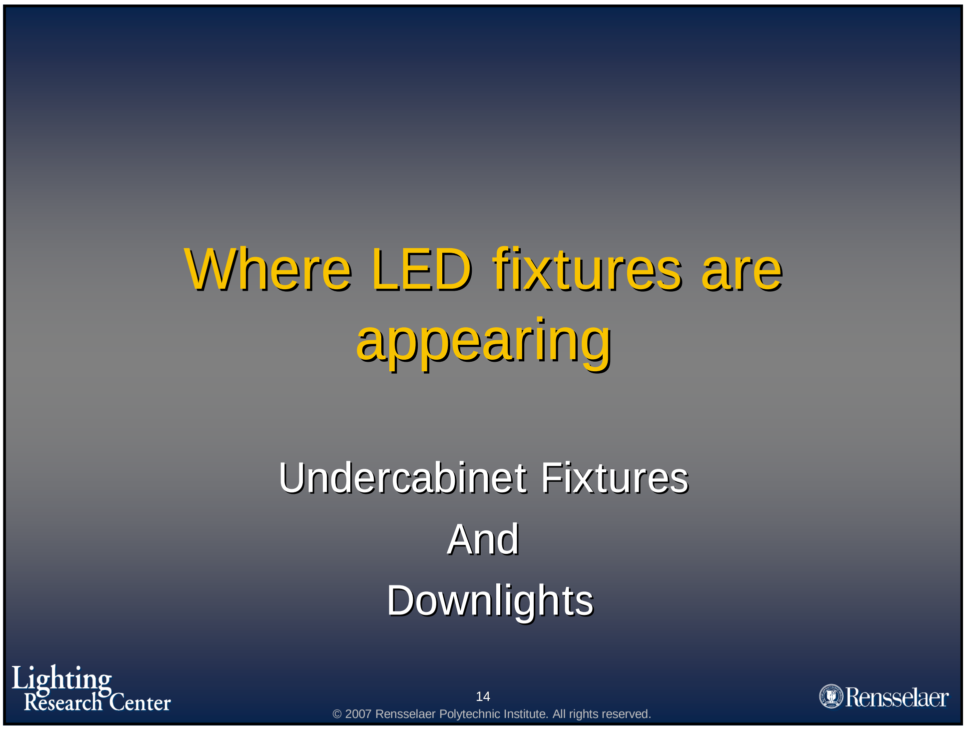
Where LED fixtures are appearing
Undercabinet Fixtures
And
Downlights
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Undercabinet

Linear, clusters, puck

Bi-level switching

5mm or high power

Tunable white

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Warm is not warm is not warm

- Standards?

61 cm (24 in) high power

LED "warm white" fixture

Uniformity on counter: 3:1

61 cm (24 in) 5 mm

LED "warm white" fixture

Uniformity on counter: 22:1

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Downlights
Replacement lamps
Fixtures and lamps
Important Questions to Ask
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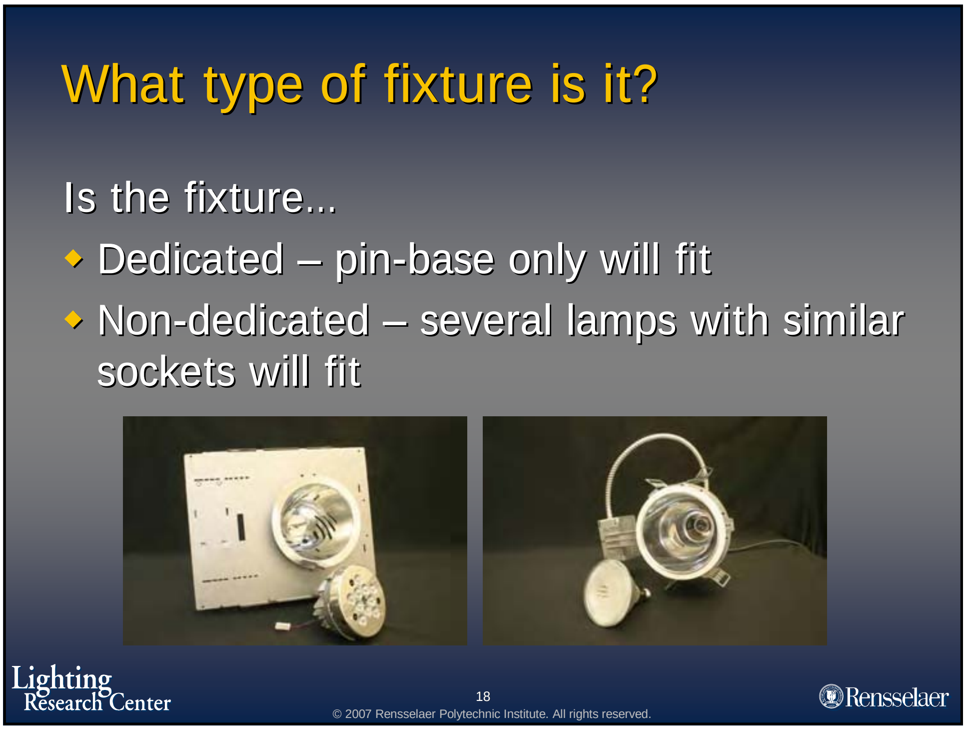
What type of fixture is it?
Is the fixture...
Dedicated – pin-base only will fit
Non-dedicated – several lamps with similar sockets will fit
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How will type of installation affect quality and life?

- Under perfect conditions, LEDs may operate 50,000 to 100,000 hours
- But - life can be drastically shortened due to poor fixture design or installation
- Most common threat to LED lighting quality and life is heat

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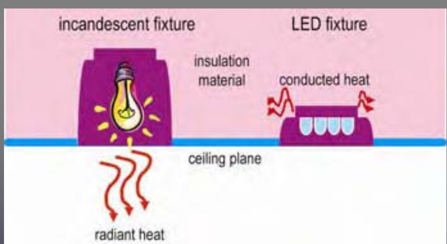
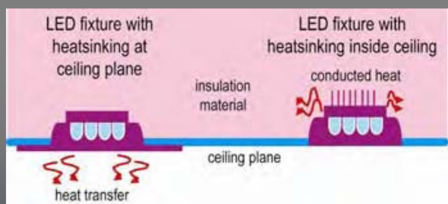
How will it be installed?

- Since heat affects fixture performance, how will it be installed – open air, semi-ventilated, enclosed?



Heat transfer for an incandescent fixture and an LED fixture



Heat transfer for two LED fixtures with different heat sinking options

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What is the lifecycle cost compared to other technologies?

- Lifecycle cost considers the overall price of a lighting fixture or system, including:
  - initial purchase cost
  - installation cost
  - operating cost over the life of the system
    - overall power usage of the system
    - average life of the fixture
    - need for lamp replacement

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What is the lifecycle cost compared to other technologies?

- Most LED fixtures have an initial purchase cost approximately 6 to 10+ times higher than the cost of incandescent or fluorescent fixtures
- Higher cost due to its
  - newness in the market
  - technology costs
  - novelty factor
- LED fixture prices expected to drop as the technology matures

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What is the lifecycle cost compared to other technologies?

- How much it will cost to light the space?
- If an LED fixture produces less light than a comparable fixture with traditional light source then it may not be as cost-effective

Less light output per fixture =

More LED fixtures to provide appropriate amount of light =

Increased purchase cost and total lighting operating cost for the space

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What is the quality and quantity of light?

- Light level
  - How much light is the fixture producing and how much is reaching the intended task area?
- Lighting uniformity and distribution
  - How even is the lighting and how much coverage is there over work space?
- Lighting color
  - Is the light warm, cool or neutral?
  - How do the colors of objects being lighted appear?
  - Can the color change for the purpose of mood lighting?

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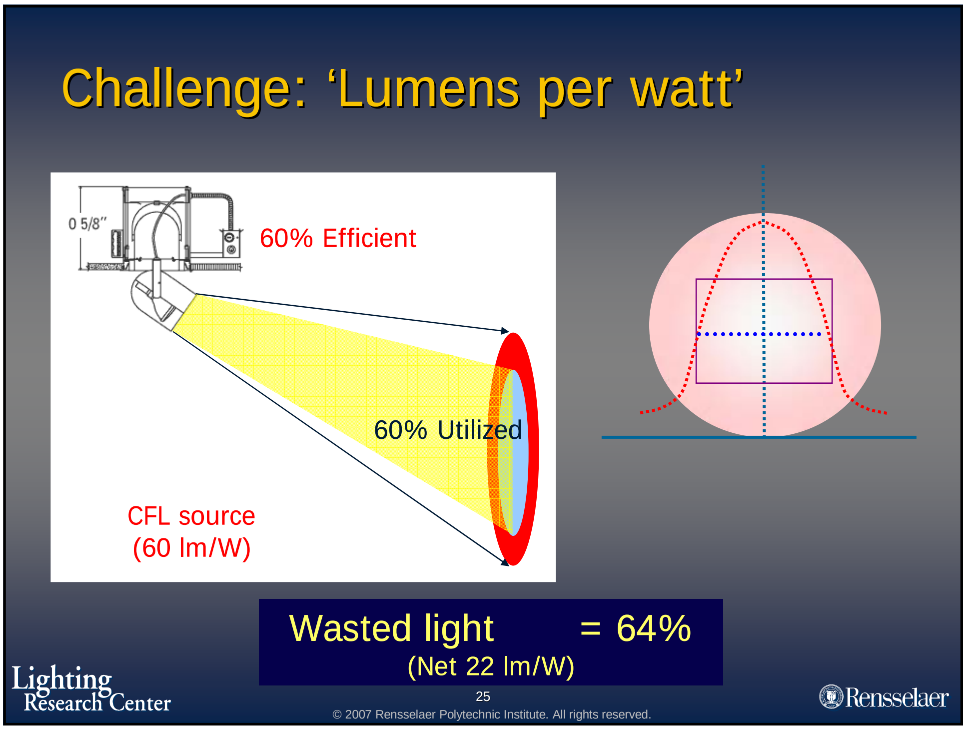
Challenge: 'Lumens per watt'
0 5/8"
60% Efficient
60% Utilized
CFL source
(60 lm/W)
Wasted light = 64%
(Net 22 lm/W)
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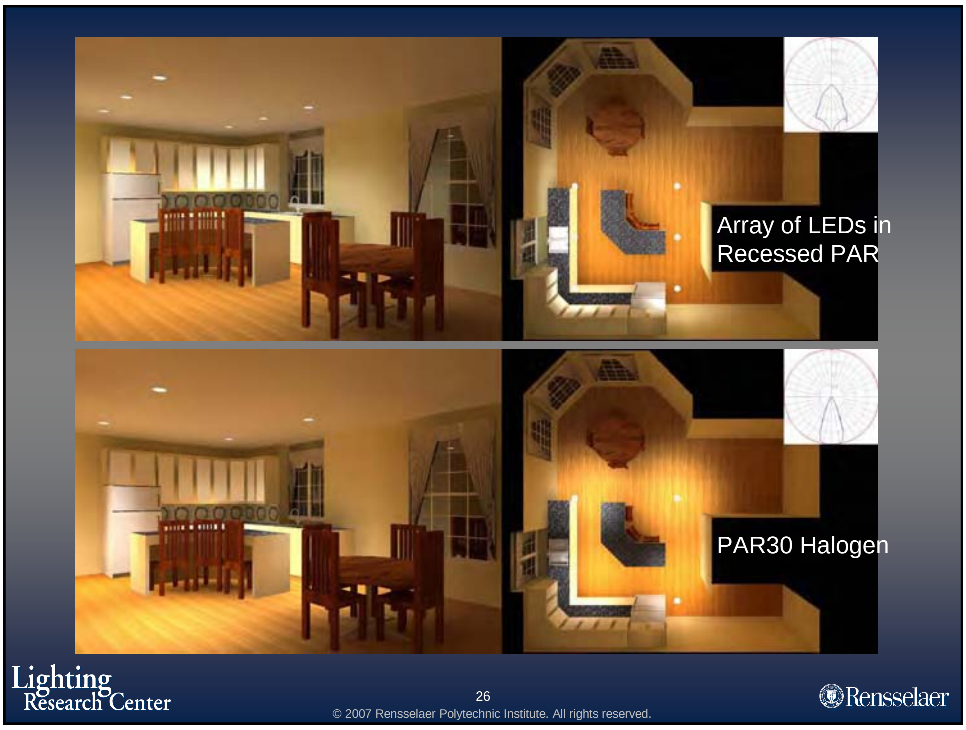
Array of LEDs in Recessed PAR
PAR30 Halogen
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How long will it last?

- LEDs fade over time rather than burning out
  - at some point the amount of light coming from the fixture will be too low to be useful.
  - This point is considered as the LED's end of "useful life"
- Calculate life using the manufacturer's life rating
  - Example: if downlights are on for 3 hours a day, an LED fixture rated to operate 30,000 hours before reaching 70% of its initial light level theoretically will last about 27 years
- In reality, other components within the fixture may burn out earlier, giving the fixture a shorter life than calculated

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How Long Will it Last?

- Will the LED fixture be easy to replace if one fixture burns out?
- Will the manufacturer have replacement products available at the end of the fixture's rated life?

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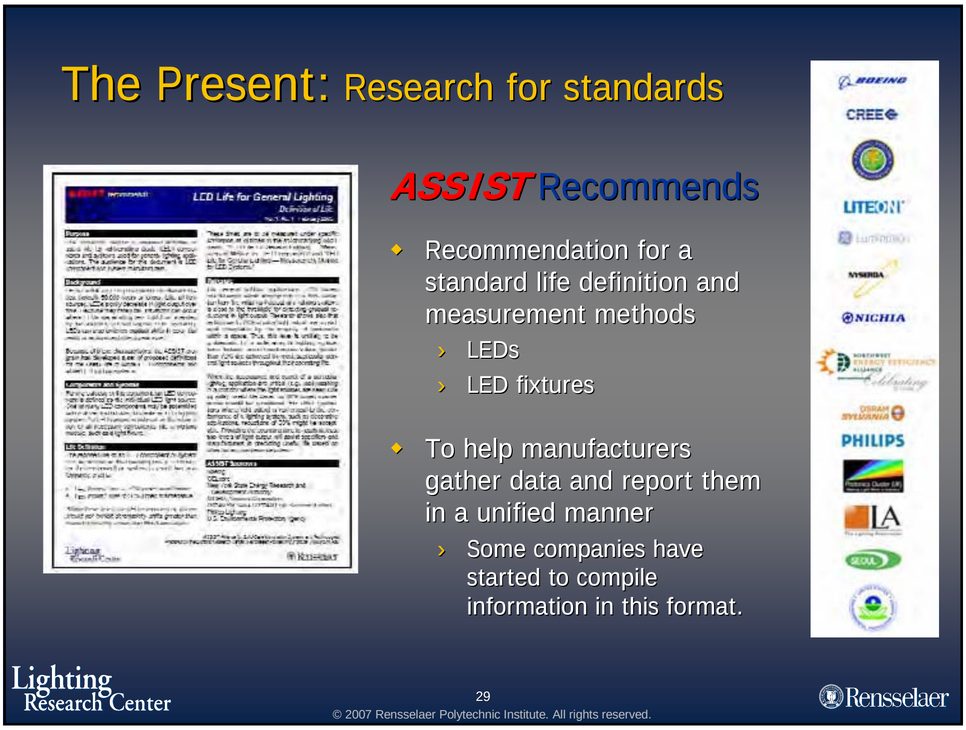
The Present: Research for standards
ASSIST Recommends
Recommendation for a standard life definition and measurement methods
LEDs
LED fixtures
To help manufacturers gather data and report them in a unified manner
Some companies have started to compile information in this format.
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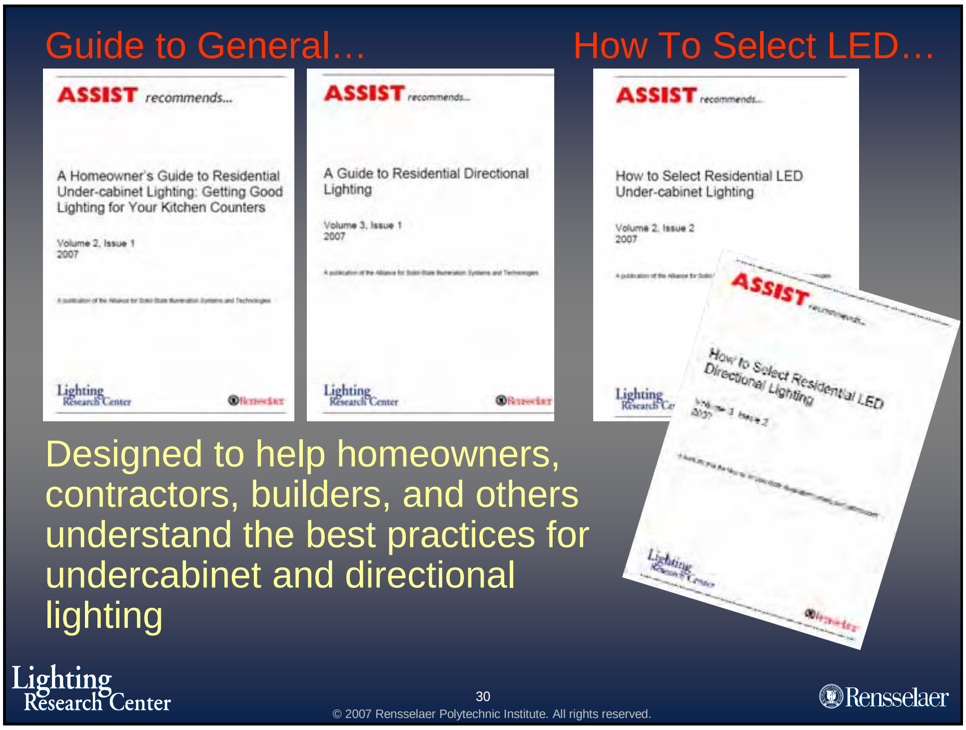
Guide to General…
How To Select LED…
ASSIST recommends...
A Homeowner's Guide to Residential Under-cabinet Lighting: Getting Good Lighting for Your Kitchen Counters
Volume 2, Issue 1
2007
ASSIST recommends...
A Guide to Residential Directional Lighting
Volume 3, Issue 1
2007
ASSIST recommends...
How to Select Residential LED Under-cabinet Lighting
Volume 2, Issue 2
2007
ASSIST recommends...
How to Select Residential LED Directional Lighting
Designed to help homeowners, contractors, builders, and others understand the best practices for undercabinet and directional lighting
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Recommendations for Testing…

Written for fixture manufacturers and provides recommendations for testing under-cabinet and directional lighting fixtures, regardless of light source

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Future Perfect?

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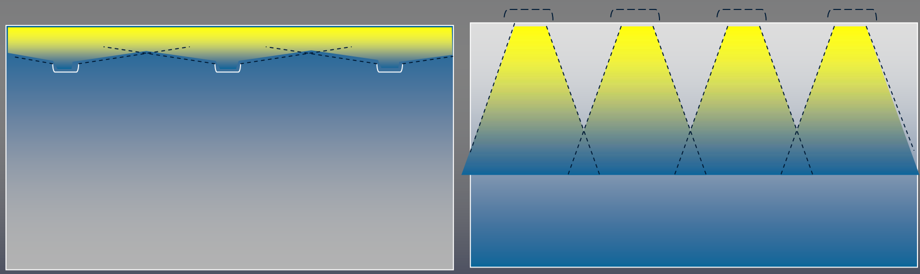
"Fixt"ures

- We are dynamic in a static environment
- Shouldn't our lighting also be dynamic?



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The Future

- Current Construction Process
  - Lighting decisions must be made early, before interior design or furnishing decisions

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The Future: a new infrastructure

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The Future

Change your mind – change your lighting

- Exploiting the strengths of LED technology and providing value to the end user would yield greater benefits and widespread use

Occupants can change the location of light fixtures or introduce new fixtures on a whim to satisfy their needs or their mood

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Time To Be Bold & Look Ahead

www.photos.com

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…LEDs will ultimately win on STYLE!!!

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Thank You!

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Niche by Niche, LEDs Offer Excellent Service and Savings

JRC LED Workshop
Ispra, Italy, May 2007

Kathryn M. Conway
LED Consulting
Nassau, NY USA

Goal & Objectives

To collaborate with you to serve the urgent, worldwide need for energy-efficient lighting.

Objectives:

- **Share ideas and resources;**
- **Stimulate new LED lighting systems; and,**
- **Send a signal:**

"Think LEDs"
(not just CFLs!)

Vocabulary

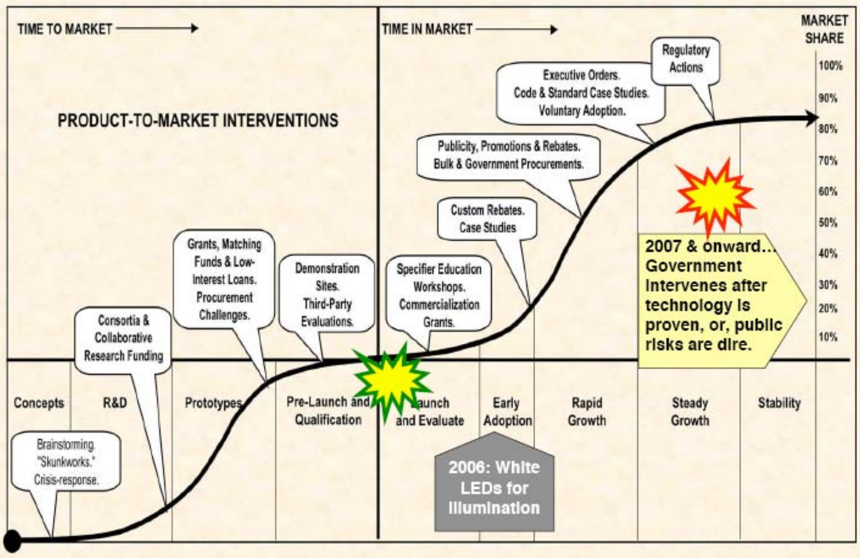
Niches:

•Well-defined performance requirements & specific light sources, luminaires and/or controls.
•Can be costly to support due to technical service demands.
•Marketing strategies geared to narrow industry segments.
•Some niches regulated by local, national or trade interests.

General Illumination:

•Ambient light provided by generic lamps and lighting systems.
•Enables people to recognize spaces, move about with ease, identify and interact with people and items of interest, accomplish basic tasks of moderate visual demand and feel secure.
•Sources are not costly & supplied by many vendors.
•LEDs have entered general illumination via colorful niches.

Context: New Product to Market Curve



From Product Intros to Market Saturation:
17 Years of LED Successes

LED Product Type and Chronology	Power demand savings (as a % of conventional system)	Market interventions (rebates, etc.)	Performance recognition program	Energy, safety or hazmat codes & standards
		Single color applications		
Exit signs 1990-2000	90%	Many; widespread.	ENERGY STAR; ELI	Many fire safety codes. Some energy codes (California; USA Executive Order; Canada)
Traffic signals 1995-2001	75% to 85%	Many.	ENERGY STAR; ELI (forthcoming)	Many worldwide for life safety & transportation (not harmonized)
Retail signage 2006+	50% to 85%	Few.	???	Many local codes. Energy standards under consideration.
		General illumination "white" applications		
Residential and task luminaires 1999+	15% to 75%	Few.	ENERGY STAR; ELI (forthcoming)	Under consideration.
"Local power lighting" 2005+	*To be calculated*	IFC/World Bank/GEF/UN (forthcoming)	ELI (pending)	Under consideration.
Torches 2006+	*To be calculated, likely >70%.*	Scattered examples (LAPD)	???	Potential for hazmat consideration.

Performance Specifications
Standard Test Methods
Third-Party Evaluations

Note to manufacturers:
Please, optimize your systems, and
Be honest with your claims!

US EPA/DOE
ENERGY STAR programs

IFC/GEF
Efficient Lighting Initiative (ELI)
Quality Certification Institute

I'm usually a decade ahead of the crowd… for better or for worse!

2000
Morrell Wine Bar,
New York, NY

Cove lighting using two strands (amber and red) of LED "channel letter retrofit" product. The drivers were housed in large metal boxes. Today similar products have much smaller drivers.

1990 Luminaire immersion
1993 *The Lighting Pattern Book for Homes*
1996 ENERGY STAR!
1998 A bright idea!
2000 A patent!
2003 Downlight & Pendant Prototype
Credit: California Energy Commission PIER grant.

When I began this project in 1998, white LEDs had an efficacy of only ~7 lumens/watt, low luminous flux, and they were very expensive. Today's white LEDs are more than 10x better!

"Locally-Powered Lighting"

A Niche Opportunity for LEDs

- Name is unique & neutral (vs. "off-grid" lighting).
- Potential for high volume of unit sales.
- Offers benefits as we face global warming challenges.

Table 2. Situations for Local Power Lighting

Involuntary	Voluntary
Region has no electric power infrastructure.	"Living off-grid" for environmental or ideological reasons
Infrastructure provides sporadic power, due to supply constraints, poor distribution or temporary interruptions	Recreation: Using outdoor spaces in proximity to on-grid facilities. Camping, touring, seasonal homes, mobile homes.
Shelters and temporary housing for populations displaced by war and disasters	Building a back-up system to minimize load for emergency generators.
Failing to cooperate with peak demand signal program, thus losing power for entire lighting system.	Participating in utility's peak demand signal to go off-grid with all or part of a facility's lighting system.
Others?	Others?

"Locally- Powered Lighting"

What is the State of the Art?

Table 3. Power Sources and Types of Luminaires for Local Power Lighting

Power Source	Fuel		Photovoltaic	Kinetic	Battery Storage	
Luminaire	Liquid (kerosene, oil, diesel)	Solid (wood, paraffin, dung)	Direct, or, with battery storage	Hydro; Dynamo	One-use	Recharge
Open flame		✔				
Lantern, simple	✔	✔	O		✔	✔
Lantern, pressurized	✔					
Torch (flashlight)			✔	✔	✔	✔
Pendant		✔	O		O	O
Wall-mount		✔	O		✔	O
Outdoor	✔	✔	✔	✔	✔	✔

Key: ✔=available now; O=potential to develop.

Benchmarking Torches (Flashlights)

- Why? They are fully integrated lighting systems.
- Universally available, inexpensive & familiar.
- LEDs are rapidly displacing other light sources…

Important performance characteristics:

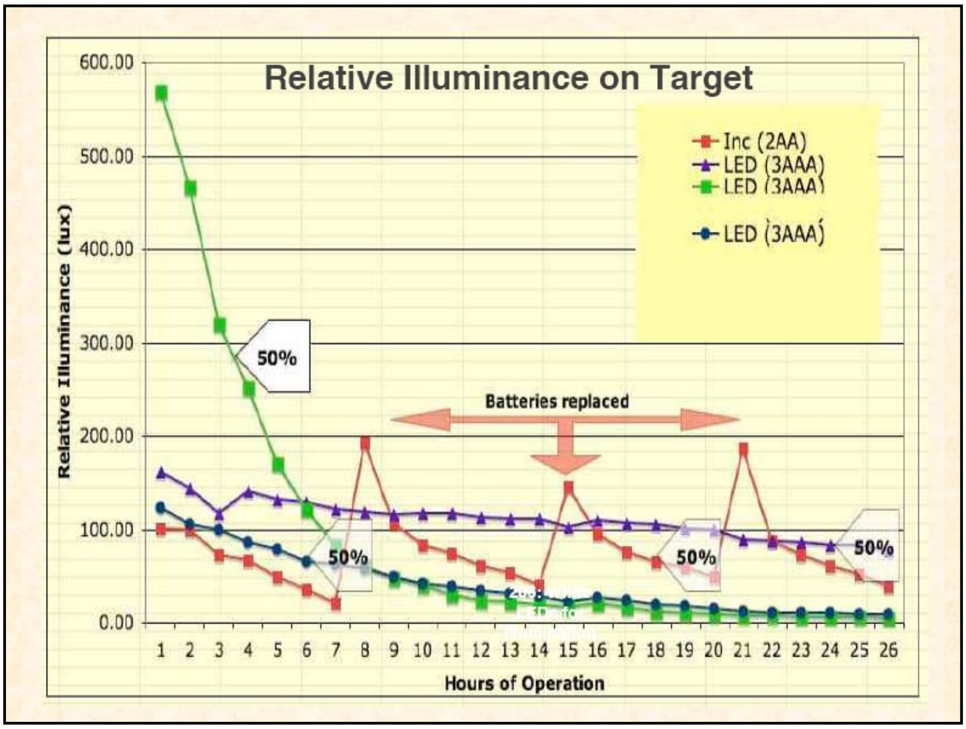
1. Illuminance at a fixed target
2. Illuminance maintenance plot
3. Useful life of light source
4. Hours of service per charge
5. Cost to operate per hour
6. Light distribution pattern
7. Control features
8. Quality of white light
9. Solid waste concerns (batteries)

Findings

- 25% of torch SKUs are LEDs, USD1 to USD30.
- Universally available, inexpensive & familiar.
- Marketing strongly skewed to adult males, *however,* women indicated they would purchase a compact, high brightness torch for <$15.

Cost to operate (10,000 hr lifetime) ranges from USD 0.06 to 0.82/hour.

Single-use batteries per 100 hours operation range from 6 (LED) to 66 (incandescent "krypton").



Summary

LEDs meet or exceed the performance of conventional torches.
LEDs are a great match for local-power lighting!

Benefits include:

- **Lower weight & more compact;**
- **Multiple control features (dimming, blinking, color options, constant light output circuits);**
- **Competitive first cost but much lower operating cost.**
- **Far fewer batteries, or, option to recharge locally.**
- **No bulb replacements needed.**
- **Huge potential market, with many types of applications and purchasers (industrial, commercial & residential).**

What's Next?

1. Locally-powered lighting is a global necessity.
2. Presently it is very expensive, polluting, wasteful & does not offer good service.
3. Let's displace the old technologies with LEDs.

We could…

- Devise flexible, modular, local power lighting systems to meet diverse needs and populations.
- Design fun, attractive new systems to appeal to the digital generation.
- Ban the use of incandescent lamps in torches.
- Offer a safer, brighter alternative to burning fuels.
- Free up operating funds for other uses.

I welcome your comments and ideas.
Thank you!

International Workshop on
Status, Prospects and Strategies for LEDs in General Lighting
Ispra, Italy – 3 & 4 May 2007

Energy Performance and User Preferences for LED Lighting for Offices and Residential Buildings

D.Sc. Eino Tetri

HELSINKI UNIVERSITY OF TECHNOLOGY
Lighting Laboratory

Content

- Introduction
  - Efficacy of today
  - Trends in lighting
- LED Luminaire with Adjustable CCT
  - Subjective Preferences for LED Lighting
- Demonstration of LED Lighting for Residential Buildings
- Conclusions

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Research Areas of Lighting Lab

- Indoor Lighting
  - Office lighting systems
  - Artificial lighting and daylighting controls
  - Lighting and productivity
  - Visual performance
  - Daylighting glare measurement
  - User perspectives and requirements
- Traffic Lighting and Vision
  - Road and street lighting
  - Vision at low light levels
  - Spectral sensitivity in the mesopic range
  - Visibility of flashing lights
  - Signal lighting
  - Road and street lighting measurements
- Light Sources and Energy
  - Characteristics of lamps and ballasts
  - The effect of dimming and cathode heating on lamp life
  - The use of LEDs in lighting
  - The electricity use of lighting
- Lighting Measurements and Testing
  - Spectrum and colour measurements
  - Photometric calibrations
  - Outdoor and indoor lighting measurements
  - Motor vehicle, road traffic lamps and retro-reflectors, aeronautical and maritime lighting devices
- Electrical Building Services
  - Home and Building Electronic Systems
  - Home Automation and Networks
  - Building Automation

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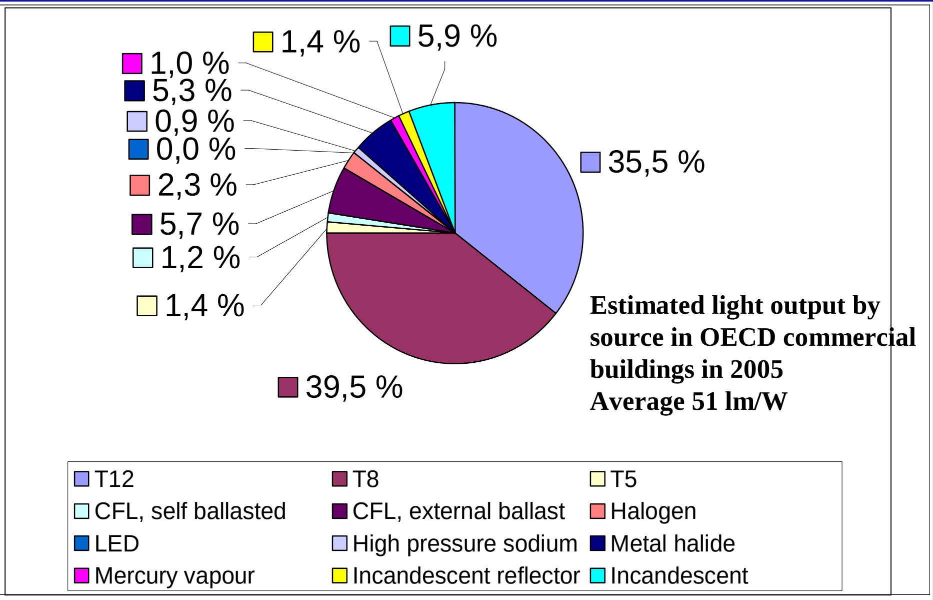
Light output by source



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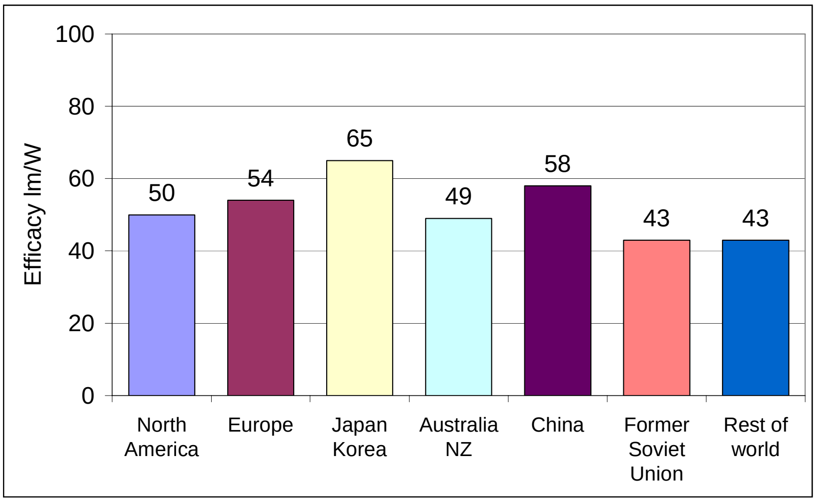
Source: IEA 2006, Light's Labour's Lost

Average lighting system efficacy by region



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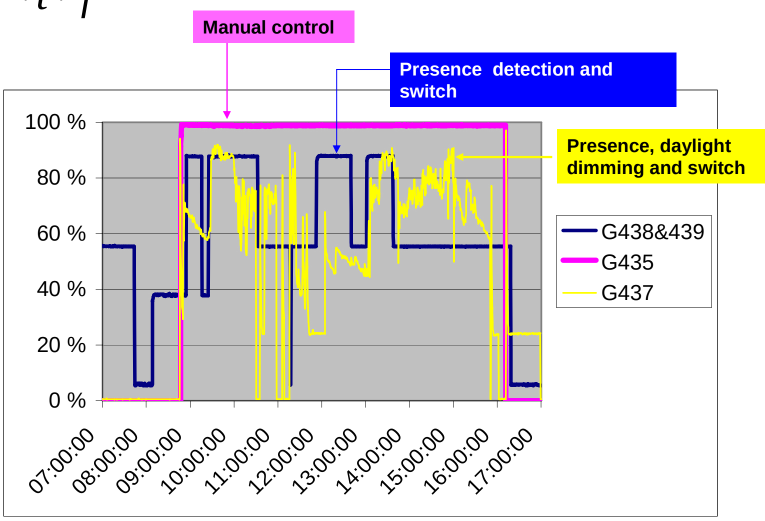
Source: Light's Labour's Lost, IEA

Power curve: dependent on control system applied

$$W = P \cdot t \cdot f$$



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Biological effects

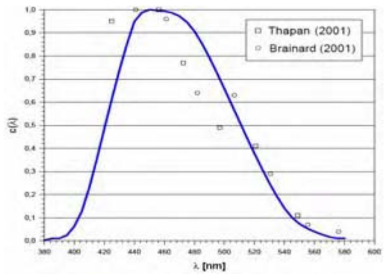
2002 David Berson et al.:

– **Third photoreceptor ipRGC ’i**ntrinsically **p**hotosensitive **R**etinal **G**anglion **C**ell’,

– Light has visual and non-visual effects

– Biological effects mean that lighting has a positive influence on health, well-being, alertness

– Spectral biological action curve based on melatonin suppression



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Mixing coloured LEDs

– More complicated structure and control

– Differences in colour rendering

– Better luminous efficacy

– Good colour rendering

– Characteristics can be changed

– Colour temperature of white light can be changed

– Performance during operation

- Influence of temperature
- Influence of electric current
- Long time stability (flux, spectra)

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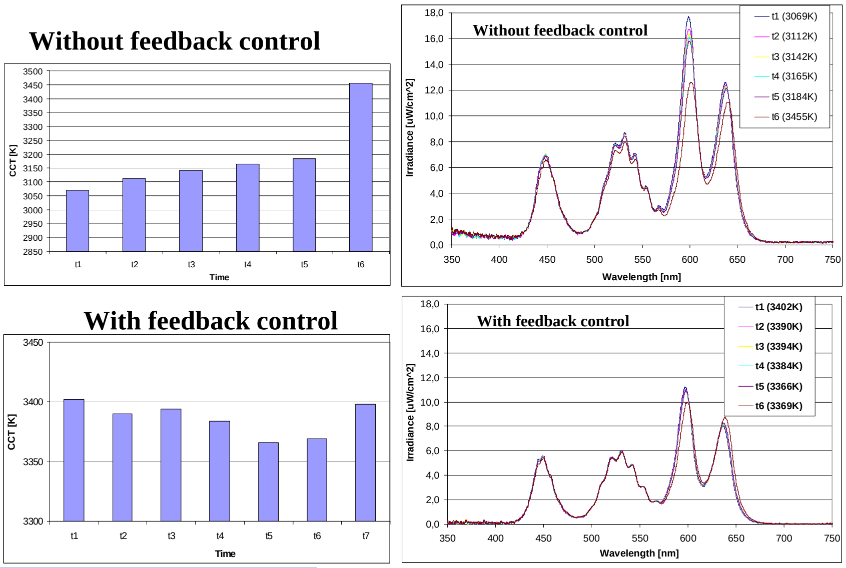
LED Luminaire with Adjustable CCT



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Control of CTT and intensity

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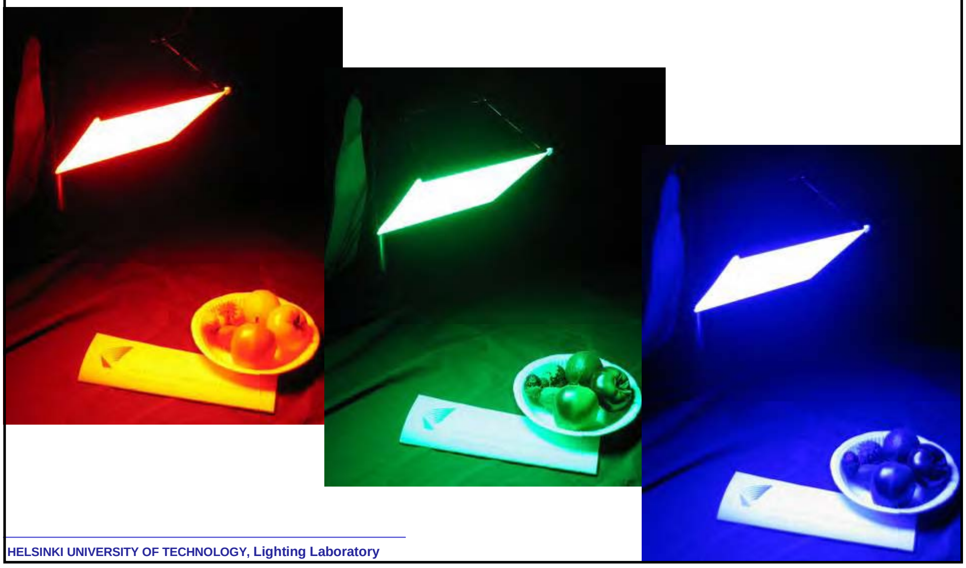
Control of Colour



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Experimental setup

CFL LED Halogen

Test questionnaire

	Strongly dislike			Neutral			Strongly like
	-3	-2	-1	0	1	2	3
General preference							
Magazine							
Soda can							
Fruits							
Skin tone preference							
Reading task							
Colour Chart							

Photometric values

Light source	**E** [lux]	**CCT** [K]	**CRI**
CFL	238	2875	83
Halogen	237	2843	98
LED	238	3370	75

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Test persons

Male	Female	Total	Age
20	8	28	21 - 51

Normal colour vision (not tested)
11 wear glasses
4 different nationalities

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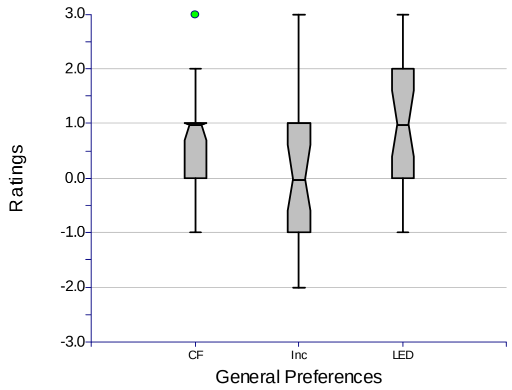
Results, general preferences



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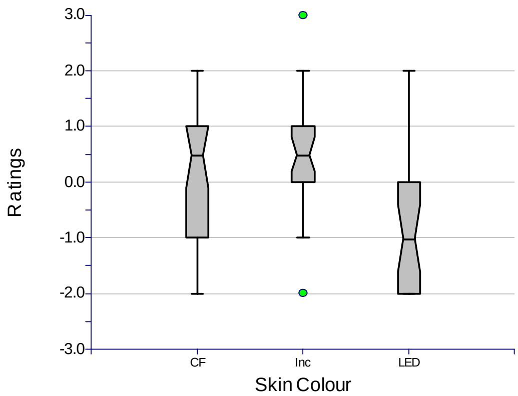
Results, skin colour



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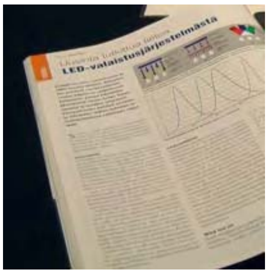
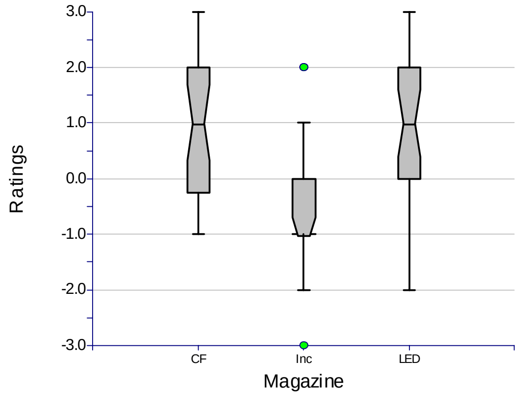
Results, magazine





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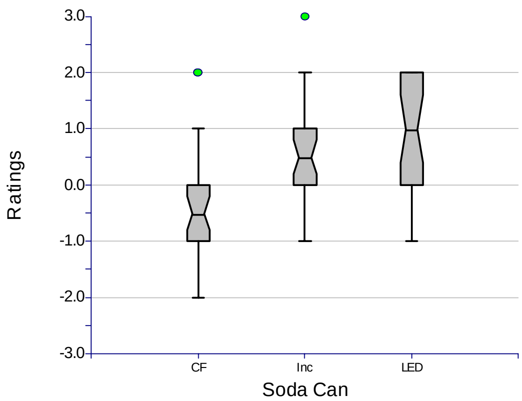
Results, soda can



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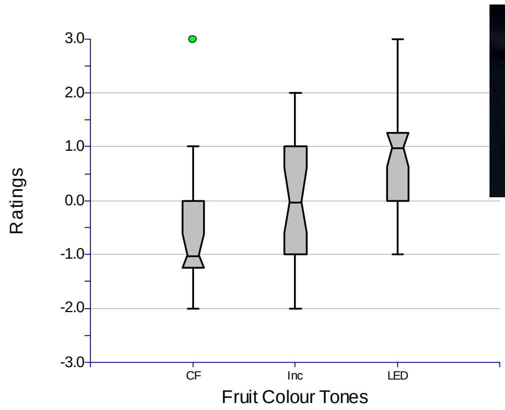
Results, fruit colour tunes



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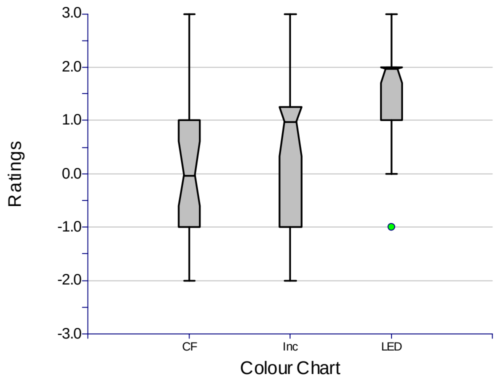
Results, colour chart



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ASTAT – Building services on residential sector

Demonstration of LED Lighting for Residential Buildings

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ASTAT demolighting

Society of working life efficiency Rajamäki

– Kitchen
– Bathroom

– Replacement of ordinary solutions with LEDs
– New lighting solutions

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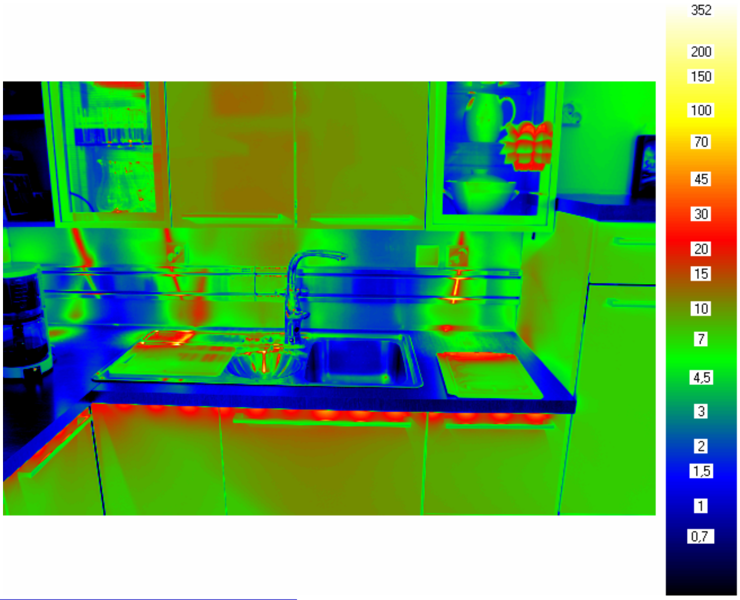
3 LEDs 1 W

Glass cabinet and profiles

Luminances cd/m²



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IR-switch to light control

Kuva: Lapetek Oy

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Profilelights

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Profilelights

Drying cupboard 2 fixtures 1 W

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Corner cupboard 2 lights 1W

Subjective evaluations

Test person	1	2	3	4	5	6	7	8	9	10	11	12	Ave
Age	55	40	31	72	29	38	42	50	30	84	64	58	**49**
Appearance	7	9	10	9	10	10	10	10	10	10	10	10	**10**
Colour/tone of the light	4	6	10	10	10	3	8	4	10	5	10	10	**8**
Glare	10	10	10	8	10	10	10	10	10	10	10	10	**10**
Brightness of the working plane	2	4	4	5	3	8	9	9	5	5	2	5	**5**

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Bathroom, 2 1W RGB-LED

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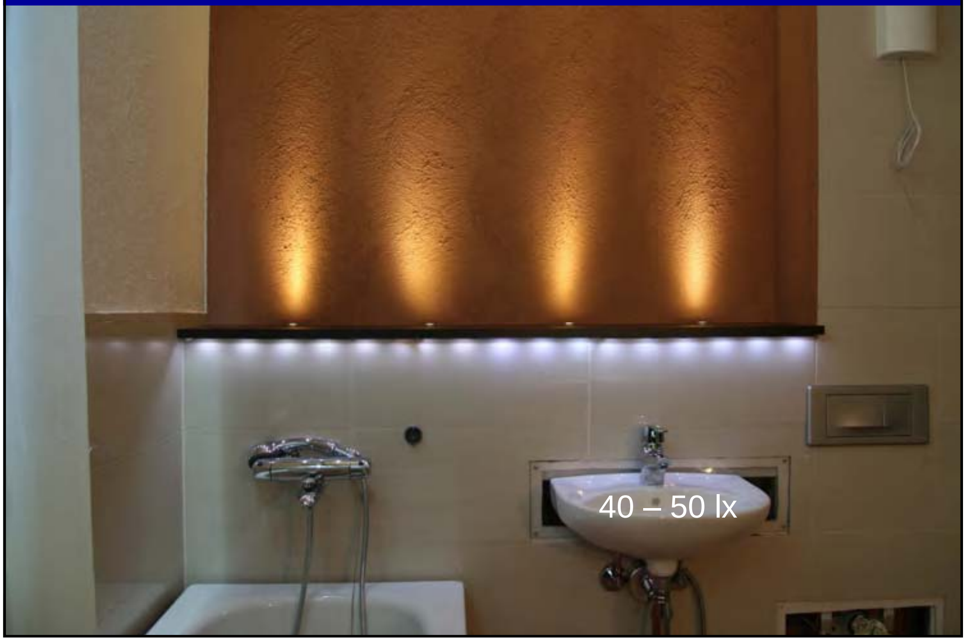
Bathroom



LEDs compared to other light sources

Power consuption: small 0.1 W- 15 W

- ***High illuminaces with directed light***

Luminous efficacy 30 - 40 lm/W

- ***Optical efficiency improves overall efficacy, light is directed to target***

Lamp life long 10000 - 50000 h

- ***Good compared to other light sources used in households***

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Conclusions

– With a good setup the perception of light from LEDs improves and people are more likely to prefer this light when compared to incandescent and fluorescent light

– The rendering of the skin color under the LEDs light is not very well accepted

– The colour rendering index does not predict the subjective preferences

– The test persons had a positive attitude to lighting in kitchen based on LEDs and they considered the lighting as interesting

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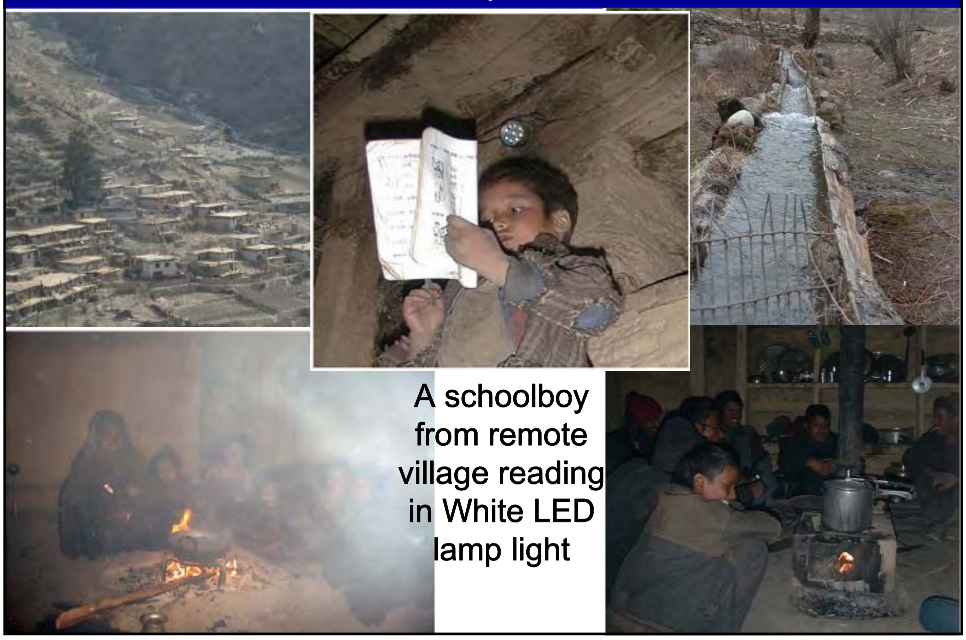
Europe-Nepal Lighting and Energy Network – ENLIGHTEN, 2005-2008



A schoolboy from remote village reading in White LED lamp light

VS Optoelectronic

International Workshop on
Status, Prospects and Strategies for LED's in General Lighting

Hotel Europe, Ispra, Italy, 3.-4. May 2007

LED's for Lighting Applications

Dipl. Ing. Christoph Cox
Product Manager
Vossloh-Schwabe Optoelectronic GmbH Co. KG

LED's for Lighting Applications

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Agenda

- **The Lighting Market for LED's**
  - Basic market split
  - Application Segmentation
    - Architectural
    - Accent decorative
    - Machine vision
    - Channel Letter
    - Illumination/general lighting
- **Major challenges in General Lighting**
  - Technology comparison to conventional light sources
  - Technology challenge efficiency, costs and CRI
- **The importance of LED-Systems in the Lighting Market**
  - Different LED's, Technologies and Power classifications
  - Quality in LED systems: thermal, electronics, optics, regulations,
  - Why need of a LED System
  - Typical LED-System structure
- **Summary**

The Lighting Market for LED’s

The lighting market for LED’s

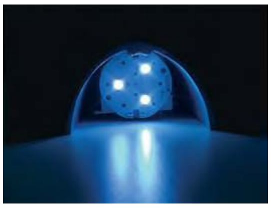
Basic market split for lighting

Products:
LED based luminaries or systems for use and sale to multiple customers

Projects:
LED products to create special lighting settings for specific illumination applications
(e.g. illumination of architecture)

The lighting market for LED's

Products: typically luminaries


Typical attributes "Products":

- long design in phase
- approvals (of luminaries) necessary
- long product life time cycle: >3 years
- stable properties over time
- light has to be planned (binning issue)
- RGB as well as mono + white
- market for general lighting

The lighting market for LED's

Projects: architectural, bars, etc.



Typical attributes "Projects":

- normally one "order"
- mainly very short delivery times requested
- difficult to plan production
- often followed by project announcement
- special requirements, sometimes to match with "standard products" ->customization necessary
- RGB as well as mono + white, but mostly RGB

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Lighting Market Segmentation by Application

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Application Segmentation

Architectural lighting:

Benefits of LED's in architectural lighting
- RGB easy possible and mainly used
- no mechanics for color mixing
- no destruction of lamp during installation
- quick color changing possible
- energy saving
- long lifetime; important when lamp maintenance is difficult

Challenges
- homogeneity of light, esp. for wall washing
- trend to sealed/encapsulated LED modules for outdoor use
- strongly project driven

Application Segmentation

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Accent, decorative: e.g. in retail, residential, spa

Benefits of LED's in decorative lighting
- easy to create a special mood by the use of colored LED's
- easy to set up eye catchers (esp. retail)
- LED's are a kind of fashion

Challenges
- warm white and high CRI needed for retail
- strongly project driven
- many small customers with low knowledge in LED technology -> systems needed

Application Segmentation

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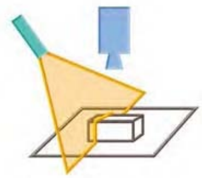
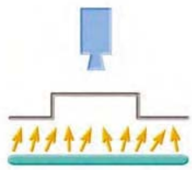
Channel Letters, Light Advertising

Benefits of LED's in Channel Letters
- alternative to glass based lamps
- small installation-height of LED-modules compared to neon
- good homogeneity for flat letters
- low power consumption + long lifetime -> cost savings
- low voltage operation

Challenges
- penetration into large letters
- humidity protection for electronic devices on LED modules

Application Segmentation

Machine Vision:


Benefits of LED's in machine vision applications
- narrow spectrum (red and near IR)
- can be installed at vibrating machines, because LED's are robust
- long lifetime: minimal downtime for production machines
- small dimensions, flexibility in design: lines, rectangles, rings of almost any size

Challenges
- highly fragmented market, hundreds of applications
- often customization necessary

Application Segmentation

Illumination, general lighting: especially high power white light



Benefits of LED's in Illumination, general lighting
- lifetime + efficiency: cost saving by regarding total cost of ownership
- lack of UV and IR in the light beam (important for merchandise)
- ability to select color temperatures

Challenges
- achieve higher efficiencies (lm/W)
- High CRI needed
- competition of conventional light sources (esp. CFL)
- cost/lm

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Major Challenges in General Lighting

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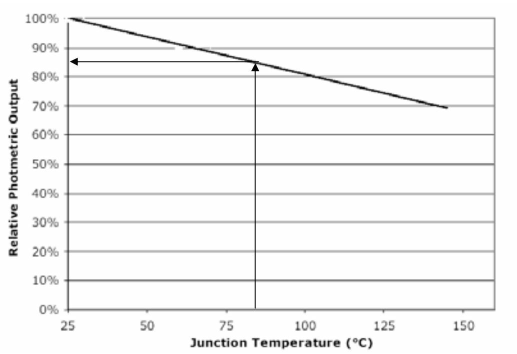
Challenges for general Lighting

Define total system efficiency of a 1W white LED

	LED
Typical Efficiency [lm/W]	Real [1] 59
Driver efficiency	80% - 90%
Luminaire efficiency	80% - 90%
Total system efficiency [lm/W]	**42**
Lifetime [h]	10.000 – 50.000

Typical Luminous Flux		
@ 350 mA	@ 700 mA	@ 1000 mA
80 lm	136 lm	176 lm



1) By using a LED with 80lm with typically 1,15 W (3,3V x 0,35A) power consumption and at "normal" (Tj = 80°C) operating conditions: 80lm x 0,85 / 1,15W = 59lm/W

Challenges for general Lighting

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Comparison to conventional light sources (white)

	LED	Incandescent	Halogen	Compact Fluorescent	Fluorescent	Metal Halide	High pressure sodium
Typical Efficiency [lm/W]	Real [1)] 59	10	20	50	75	80	120
Driver efficiency	80% - 90%	100%	100%	80% - 90%	80% - 90%	80% - 90%	80% - 90%
Luminaire efficiency	80% - 90%	30% - 50%	30% - 50%	50% - 60%	50% - 70%	40% - 80%	40% - 80%
Total system efficiency [lm/W]	**42**	**4**	**8**	**23**	**38**	**41**	**61**
Lifetime [h]	10.000 – 50.000	1.000	3.000	10.000	15.000	10.000	16.000

1) By using a LED with 80lm with typically 1,15 W (3,3V x 0,35A) power consumption and at “normal” (Tj = 80°C) operating conditions: 80lm x 0,87 / 1,15W = 60lm/W

Challenges for general Lighting

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Challenge: decrease costs

	Light Output (lumens)	Electrical inputs (watts)	Luminous efficiency (lm/W)	Lifetime (hours)	**Initial cost ($/klm)**
High Power LEDs	60-135	1,2-2,6	50-70	50.000	**26-50**
Halogen capsule lamp, 120V, bi-pin	950 140	50 10	19 14	2000 2000	**4,6** **31,5**
Incandescent, screw base	890 114	60 15	14,8 7,6	1000 2500	**0,7** **5,9**
Fluorescent T12, Fluorescent T5	2660 95	34 4	78,2 23,8	20000 6000	**1,09** **27,3**
Compact fluorescent, screw base Compact fluorescent, bi-pin	900 210	15 5	60 42	10000 10000	**4,8** **11,5**
Ceramic metal halide, screw base	3850	70	55	20000	**7,5**

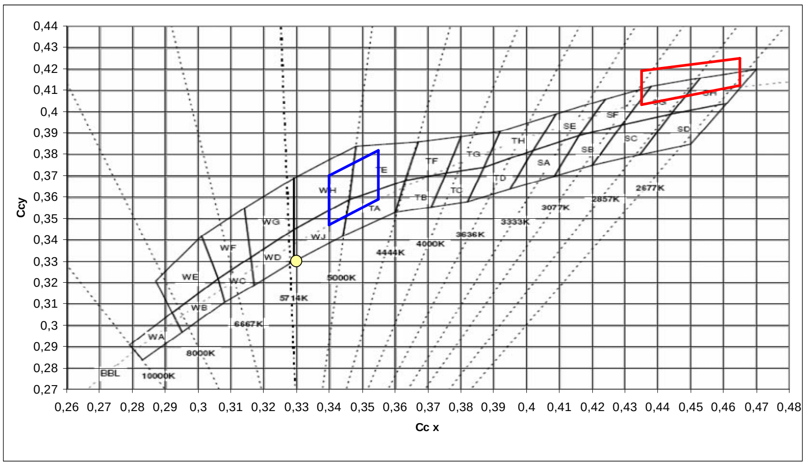
Source: Strategies Unlimited Report 2007

- Initial costs per 1000 lumens of white LED light are 2 – 50 times higher than conventional light sources
- long lifetime, energy savings, low maintenance costs can help to compensate the high initial costs of LED’s over lifetime

Challenges for general Lighting

Optoelectronic

Technology challenge “quality” of white light:
Reduction of binnings, e.g. one warm white + one cold white



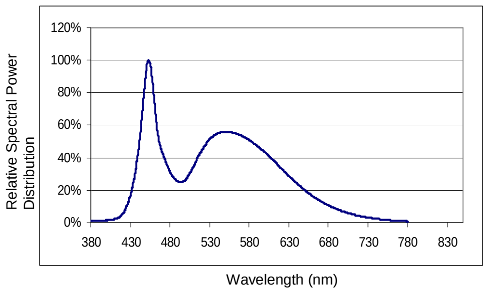
Challenges for general Lighting

Optoelectronic

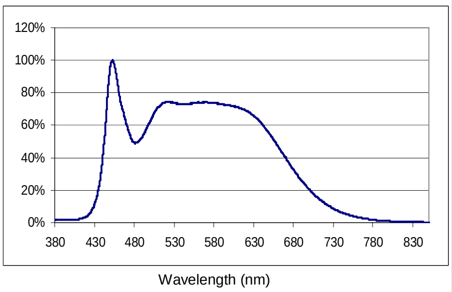
Technology challenge “quality” of white light:
High Color rendering index

- Conventional LED-solutions offer Ra between 60 and 83 (CRI-Group 2 or 1B)
- Primarily a challenge to phosphor technology
- just a few LED-lamps offer CRI >90 (CRI group 1A)

Conventional color spectrum (cool white)



High CRI color spectrum (cool white)



VS Optoelectronic

Challenges for general Lighting

Desired white LED module for luminaries

Optimized binning

two very narrow colour bins (eye can see no difference in one binning) in warm- and cool white, release customers from own binning responsibility

Min. & typical lumen value and colour coordinates at real (Tc=80°C) operating conditions

High colour rendering index (Ra > 90!)

CRI-Group 1A (max. possible)!

LED-solutions offer Ra between 60 and 83 only (CRI-Group 2 or 1B)

Homogeneous light spot due to optimized secondary optics

Optimal illumination spot without yellow ring

Different viewing angles,

No further light loss by luminary

Optimized thermal design

<3K/W thermal resistance junction to casing enables efficient luminary design with high lumen output after thermal stabilization. Customer has only to verify suggested casing temperature.

Verified lifetime

40.000h; 70% lumen maintenance at real (Tc=80°C) operating conditions

VS Optoelectronic

Importance of LED-Systems for the lighting market

Without LED Systems customer must understand…

Optoelectronic

technology

Different LED's and technologies !

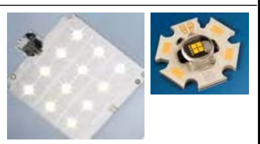
Through-hole LED devices	SMD LED devices	COB LED modules

Without LED Systems customer must understand…

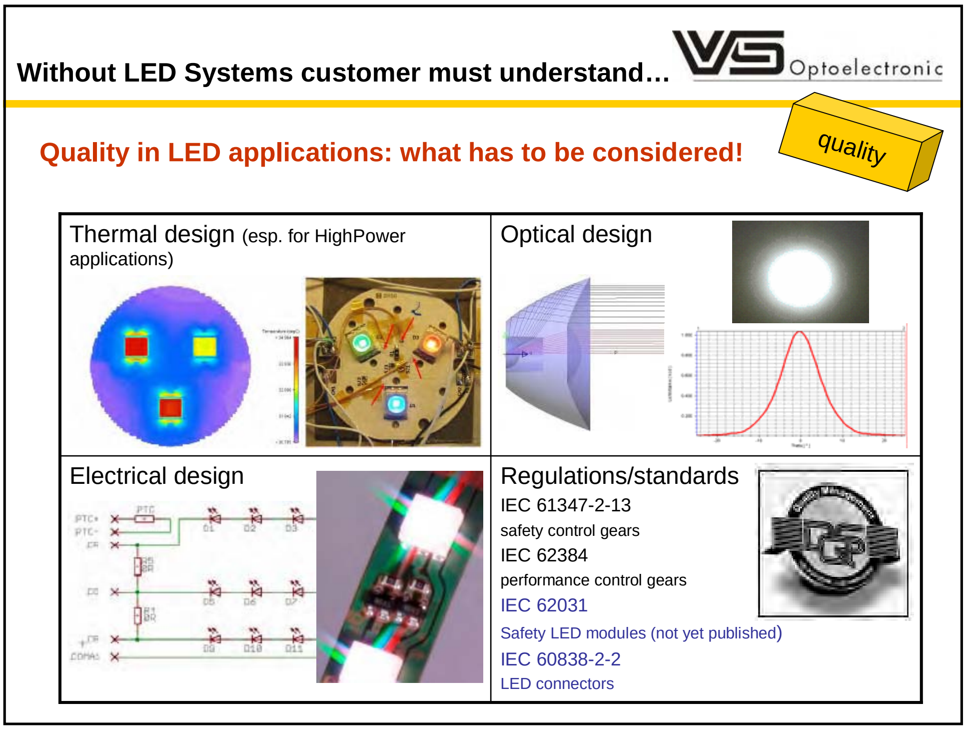
Optoelectronic

power

Different power classifications !

	Through-hole LED devices	SMD LED devices	COB LED modules
Low Power: ~ 20mA			
High Current: ~ 50-150mA			
High Power: 150mA to >1000mA			


Without LED Systems customer must understand…
VS Optoelectronic
drivers
Different ways to drive LEDs -> electronic drivers !
mains
low voltage
color control
110V / 230V
const. current


Without LED Systems customer must understand…
VS Optoelectronic
quality
Quality in LED applications: what has to be considered!
Thermal design (esp. for HighPower applications)
Optical design
Electrical design
Regulations/standards
IEC 61347-2-13
safety control gears
IEC 62384
performance control gears
IEC 62031
Safety LED modules (not yet published)
IEC 60838-2-2
LED connectors

Why need of a LED-System?

VS Optoelectronic

stable/reliable LED system:

quality: thermal, optics, electrical, regulations

technology: SMD, COB, … | power | drivers

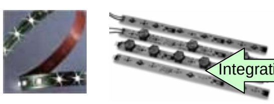
- Lighting market is strongly diversified:
  very small companies as well as large companies
- Many of typical lighting manufacturers are used to conventional lamps and have to install competence in LED technologies

or

- Enabling partners are necessary to bride these gab and offer system solutions

Typical LED-System structure

VS Optoelectronic

	LED Modules	Control Modules	Converters
voltage driven	24 V or 12V Low + High Power 	Typical interfaces: manually control DMX Remote IR DALI 1-10V  Integration possible ← → Integration possible	Different wattages (e.g. 10-130W) for different output voltages (10-24V) possible 
current driven	350mA, 700mA, 1050mA or more 		const. current drivers "mono"  const. current drivers "mono + dim. function"  Const. current drivers "3 channel RGB" 

Summary

- Market is basically spitted into “Projects” and “Products”
- Market can be more detailed segmented by applications (architectural,…)
- Major challenges for LED’s in general lighting with white light are to increase efficiency by decreasing costs and to create “high” quality light with just a few binnings and high CRI
- LED System solutions are necessary, to make LED applications possible for customers/companies with different knowledge in
  - LED technology + LED performance
  - quality issues (thermal, optical, electrical, regulations)

Thanks for your attention!

The Company

Vossloh-Schwabe Optoelectronic GmbH & Co. KG has been established in 1979 as a distributor for opto-electronic components. Today, the company is part of the Panasonic Electric Works Vossloh-Schwabe Group. With its more than 25 years of experience in the field of LED technology, VSO is the competence centre for hi-tech LED technology within the PEW VS Group.

Vossloh-Schwabe Optoelectronic GmbH Co. KG

Carl-Friedrich-Gauß-Straße 3 • D - 47475 Kamp-Lintfort

Tel.: +49/(0) 28 42/980 0 • Fax: +49/(0) 28 42/980 299

vertriebvsw@vsw.vossloh-schwabe.com

www.vs-optoelectronic.com

International Workshop on

Status, Propects and Strategies for LEDs in General Lighting

Alberto Fraser

Fraserdesign

"Successful experiences in residential and contract LED lighting"

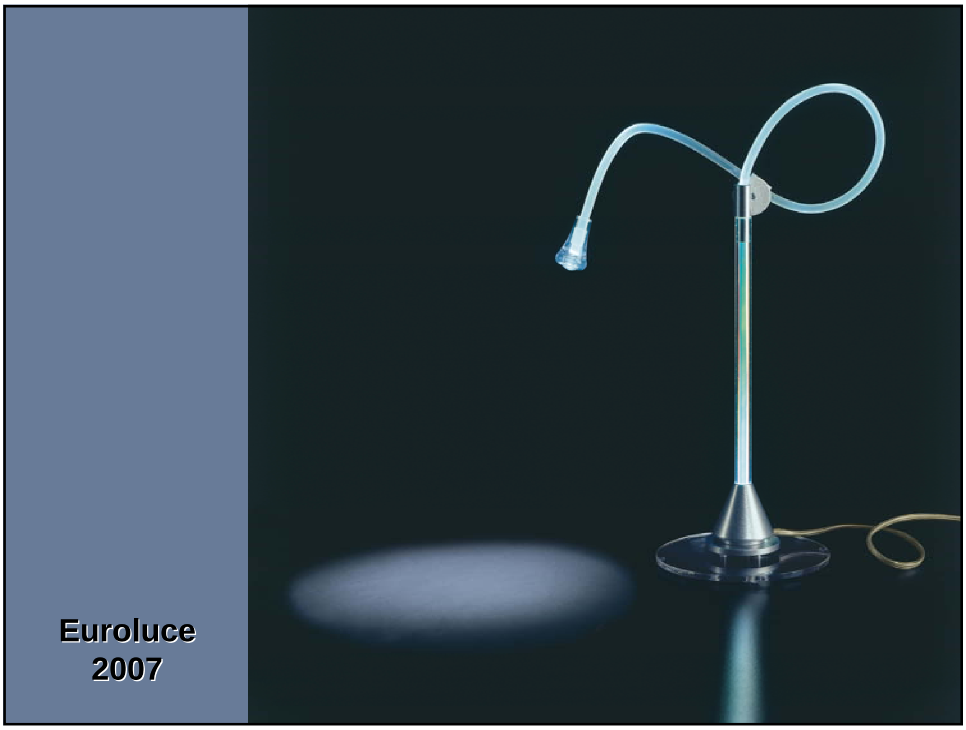
www.fraserdesign.it fraserdesign@fastwebnet.it

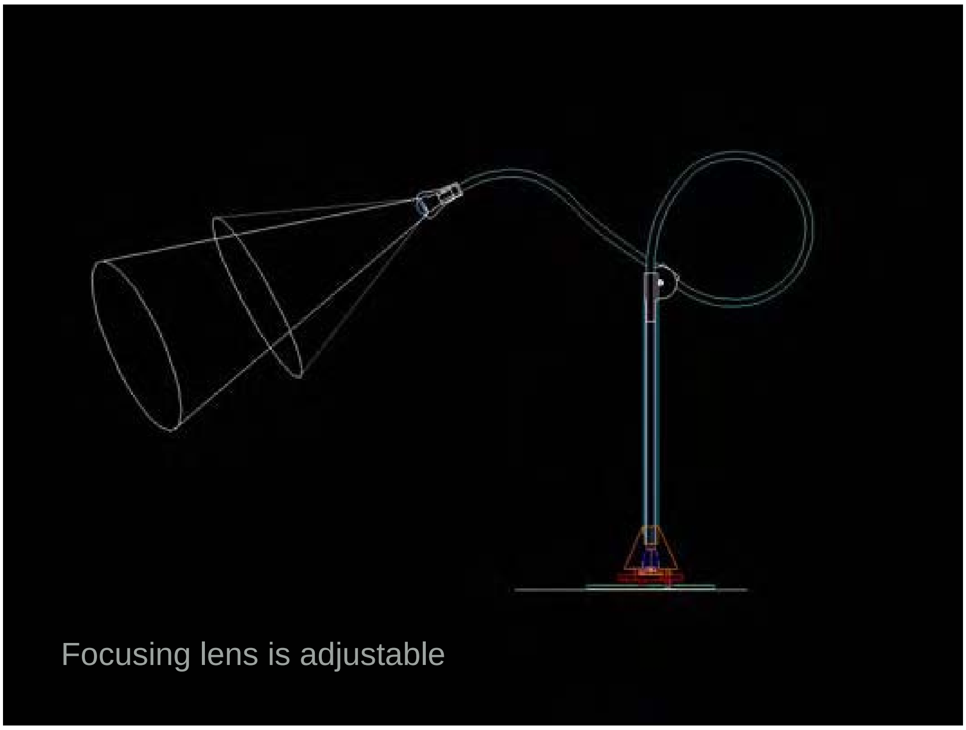
3-4 May 2007 Ispra, Italy

Photo by Miro Zagnoli

LILI' MARLENE
TABLE

- Arm: fiberoptics Ø =7 mm
- Body: clear polycarbonate sheathed with 3M light radiant film
- Gathering lens housed in aluminum base
- Focusing lens head: glass and polycarbonate
- Light source: 1X5W LED
- H. 38 cm


Euroluce
2007


Focusing lens is adjustable

An intimate reading light…

Selected for

ADI Design Index

LUXIT

LILI' MARLENE
FLOOR

- Arm: fiberoptics Ø =15 mm
- Body: clear polycarbonate with 3M light radiant film
- Gathering lens housed in aluminum base
- Focusing lens head in glass and polycarbonate
- Light source: 1X16W LED
- H. 150 cm

LUXIT

LED TRACK

FREESTANDING

For window display and table light

- Arm: transparent acrylic
- Light source: 3X3W LED

Euroluce 2007

LED TRACK *CEILING and SINGLE SPOTS*
For jewelry and small window displays

- Rotation: 290°
- Light source: 3X3W LED

LUMEN CENTER ITALIA

RIBBON

Transition from halogen to LED

Halogen version
Euroluce 2005


Cooling radiator plate designed to fit into parabola housing


A balanced
tone of light
is achieved
by combining
one strip of
warm LED
light and one
of cold
Euroluce 2007

altis
il potere della luce

Sly

Led lighting system for the contract market targeted for shop windows and niche lighting

Euroluce 2007

Sis 1

Two axial rotating spot

- LED 3 - 5 W
- Light sources from 100 to 160 lumen
- Lens 25°- 40°

Sis 2

Target rotating spot

- LED 3 - 5 W
- Light sources from 100 to 160 lumen
- Lens 25°- 40°

Sis 2 suspended

- Flush-mounted into a wall or ceiling
- Supplied with a transformer housing as a complete module

Sis 3

Low profile rotating spot

- LED 3 - 5 W
- Light sources from 100 to 160 lumen
- Lens 25°- 40°

Base track module

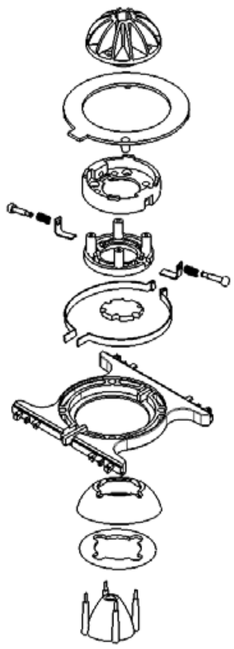
Composed of an extremely thin (**8 mm high**) connecting module in polycarbonate, in which the spots are housed, that we call "**shuttle**".

Side aluminum structural elements are supplied in **various lenghts** to create a series of four **modular solutions**.

Sly suspended cable system

Maximum flexibility of installation.

LED cable system can be mounted horizontally or vertically.



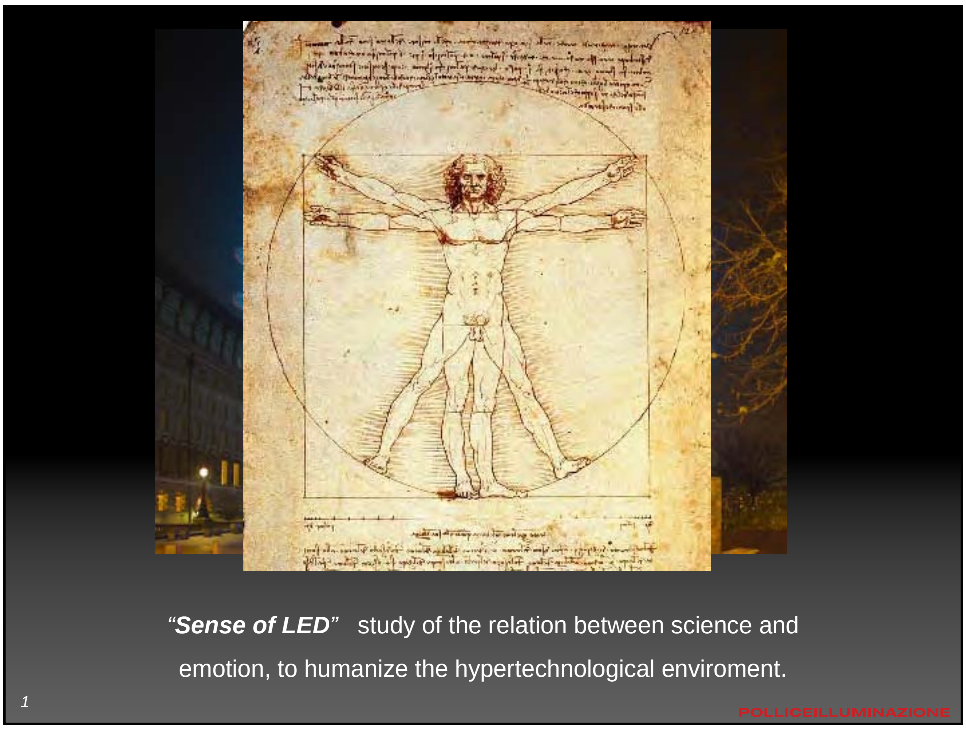
The **Sly shuttle** is a unique **patented** system which **permits** the positioning and **movement** of each spot at will, **overcoming** the fixed configuration of serial electrical connections.

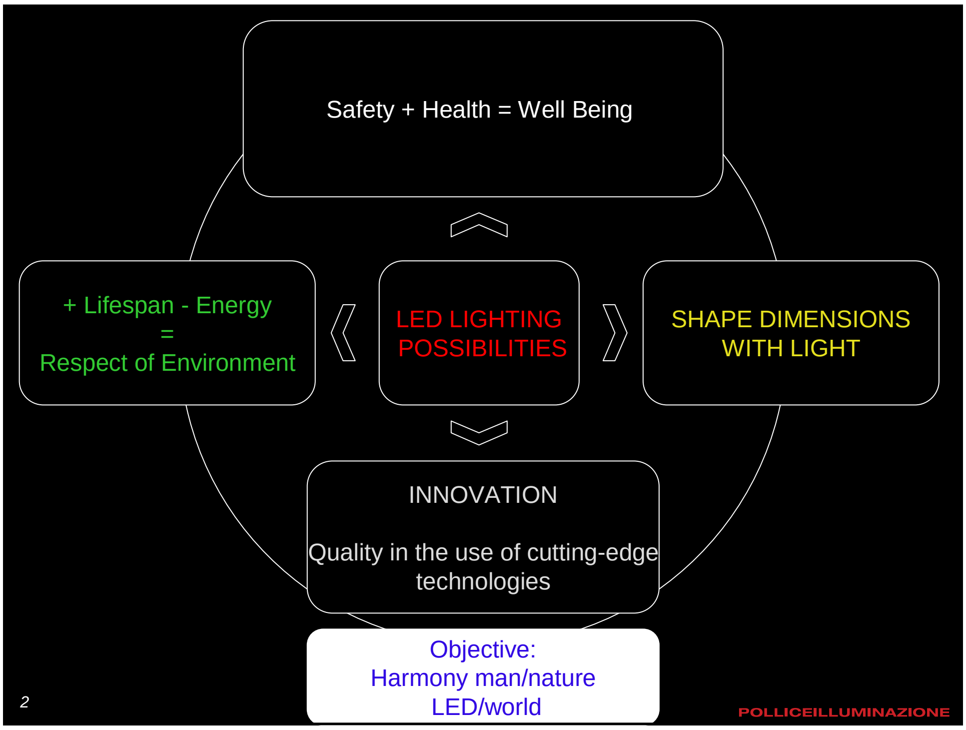
SENSE OF LED

Emotional lighting

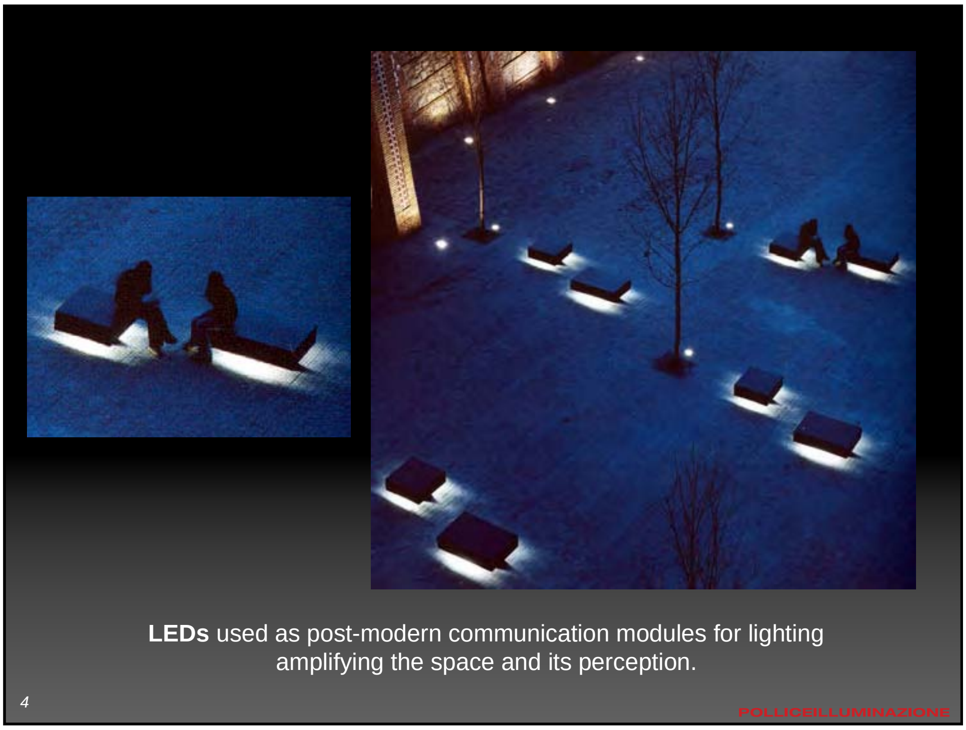
Revelation of senses

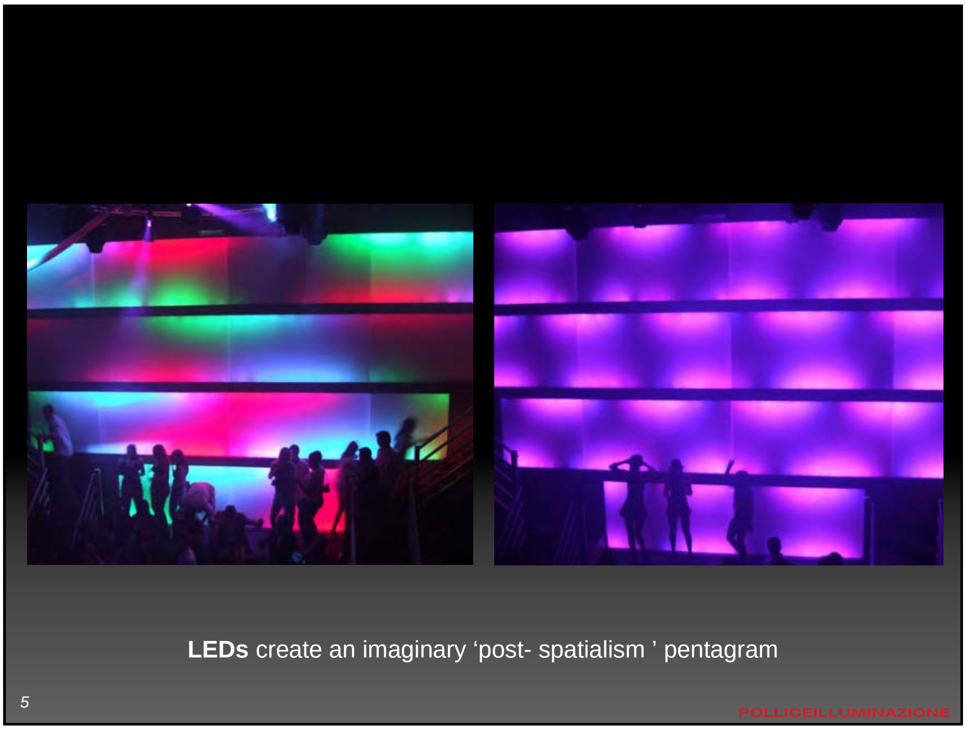
Status, Prospects and Strategies for LEDs in General Lighting
Hotel Europa, Ispra, Italy – 3 & 4 May 2007

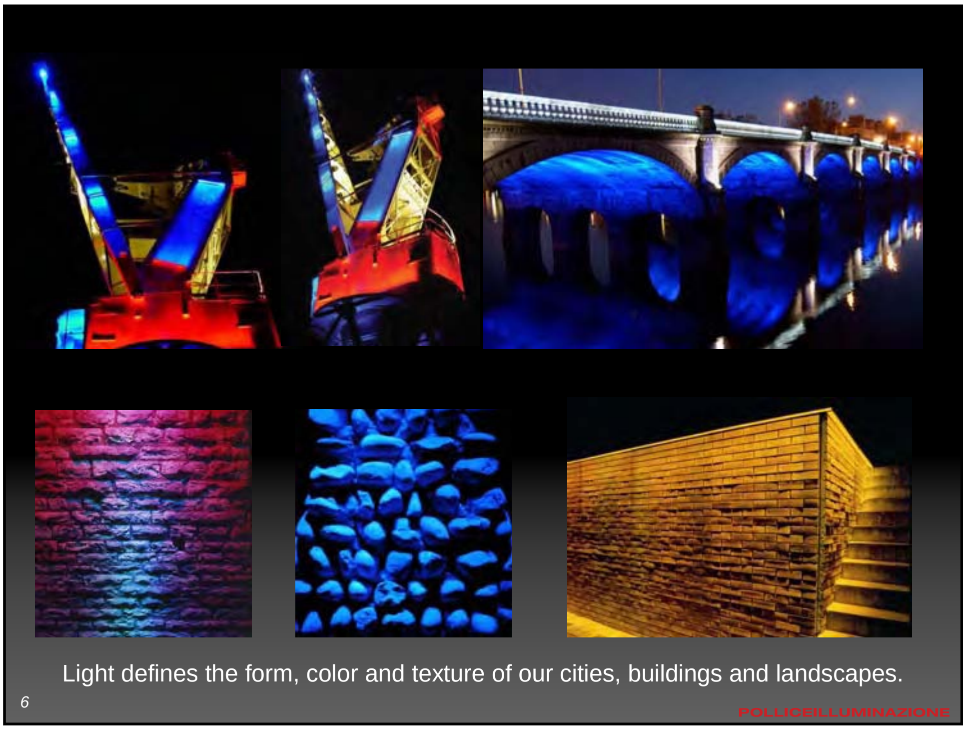

“*Sense of LED*” study of the relation between science and
emotion, to humanize the hypertechnological enviroment.
1
POLLICEILLUMINAZIONE


Safety + Health = Well Being
+ Lifespan - Energy
=
Respect of Environment
LED LIGHTING
POSSIBILITIES
SHAPE DIMENSIONS
WITH LIGHT
INNOVATION
Quality in the use of cutting-edge
technologies
Objective:
Harmony man/nature
LED/world
2
POLLICEILLUMINAZIONE


3
POLLICEILLUMINAZIONE


LEDs used as post-modern communication modules for lighting amplifying the space and its perception.
4
POLLICEILLUMINAZIONE


LEDs create an imaginary ‘post- spatialism ’ pentagram
5
POLLICEILLUMINAZIONE


Light defines the form, color and texture of our cities, buildings and landscapes.
6
POLLICEILLUMINAZIONE



*“**Sense of led** “* offers the possibility to materialize the ‘spatial concept’, already expressed by Fontana, backing on the design culture.

7

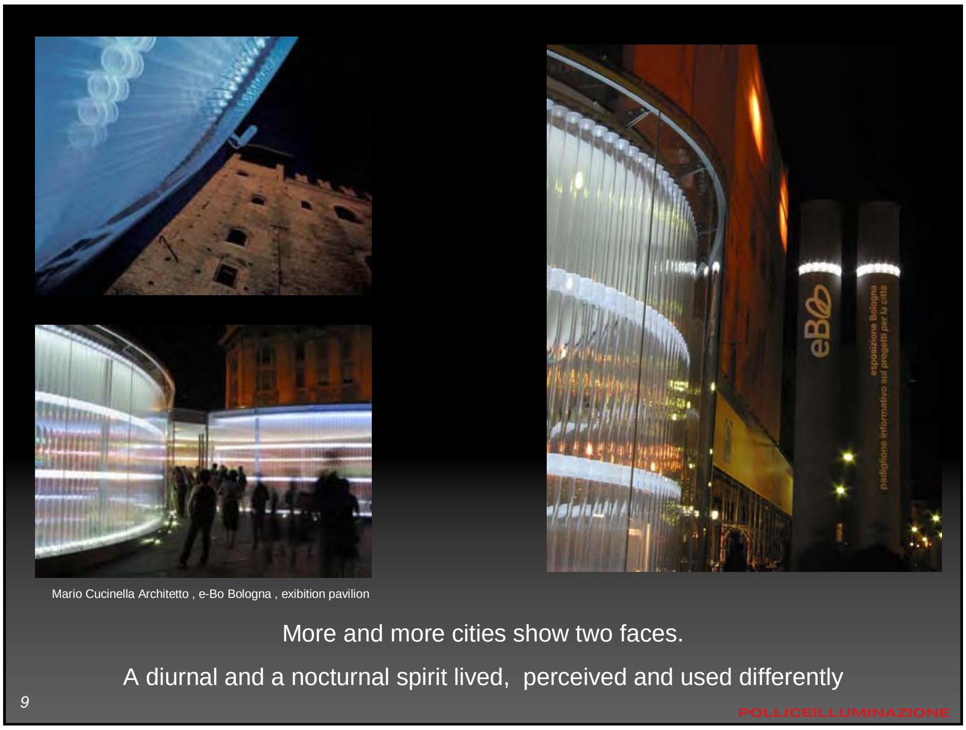
POLLICEILLUMINAZIONE

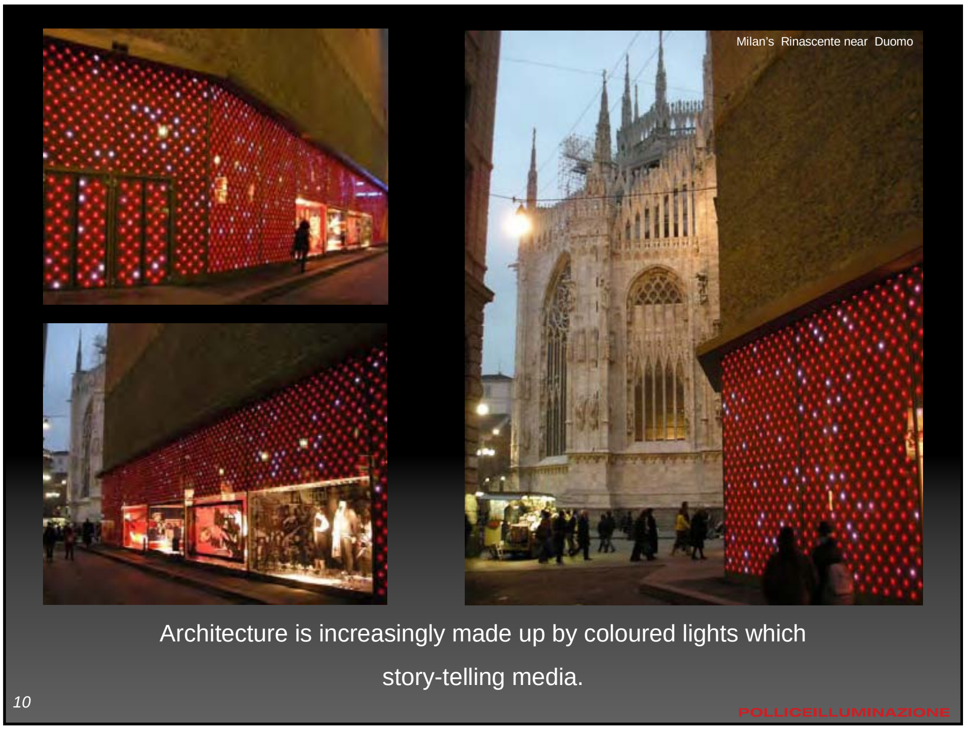

Thanks to **LED**s we perceive light as the epiphany of potential beauty.

An eternal metamorphosis transforming space,
place or dimension, and amplifying their levity and livability.

8

POLLICEILLUMINAZIONE


Mario Cucinella Architetto , e-Bo Bologna , exibition pavilion
More and more cities show two faces.
A diurnal and a nocturnal spirit lived, perceived and used differently
9
POLLICEILLUMINAZIONE


Milan's Rinascente near Duomo
Architecture is increasingly made up by coloured lights which
story-telling media.
10
POLLICEILLUMINAZIONE

Media Buildings are an answer to the continuous quest for information

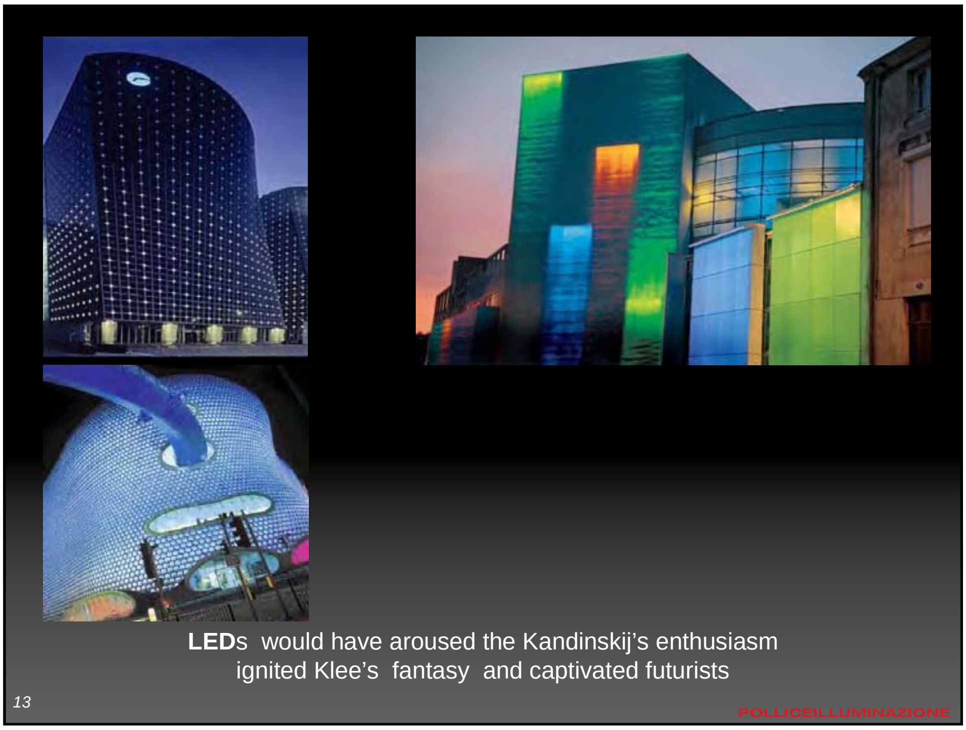
11

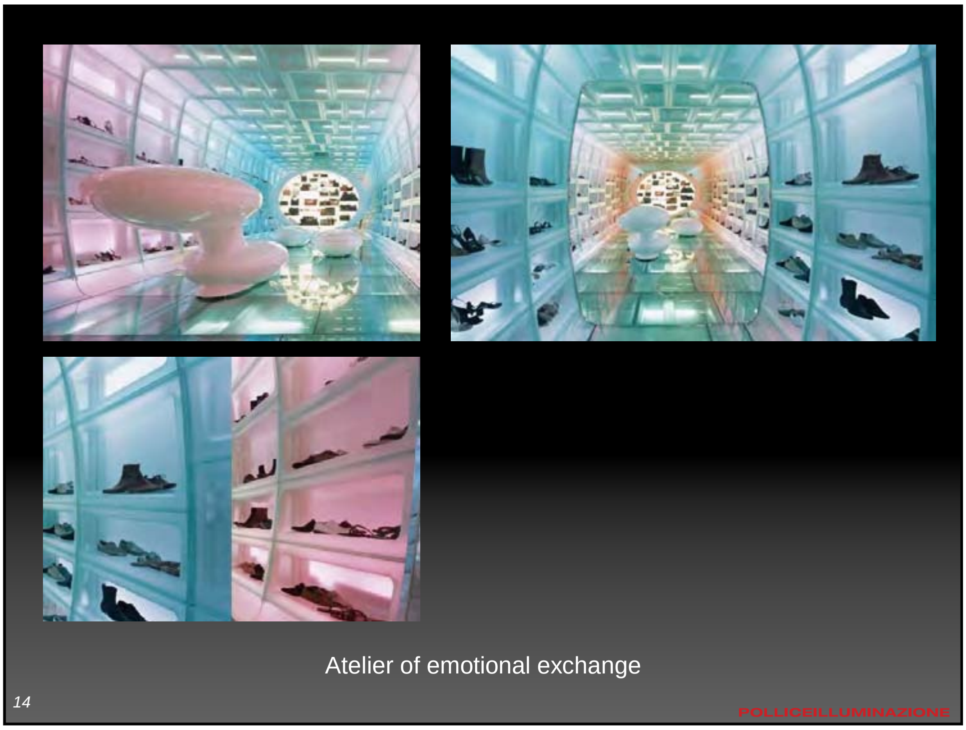
POLLICEILLUMINAZIONE

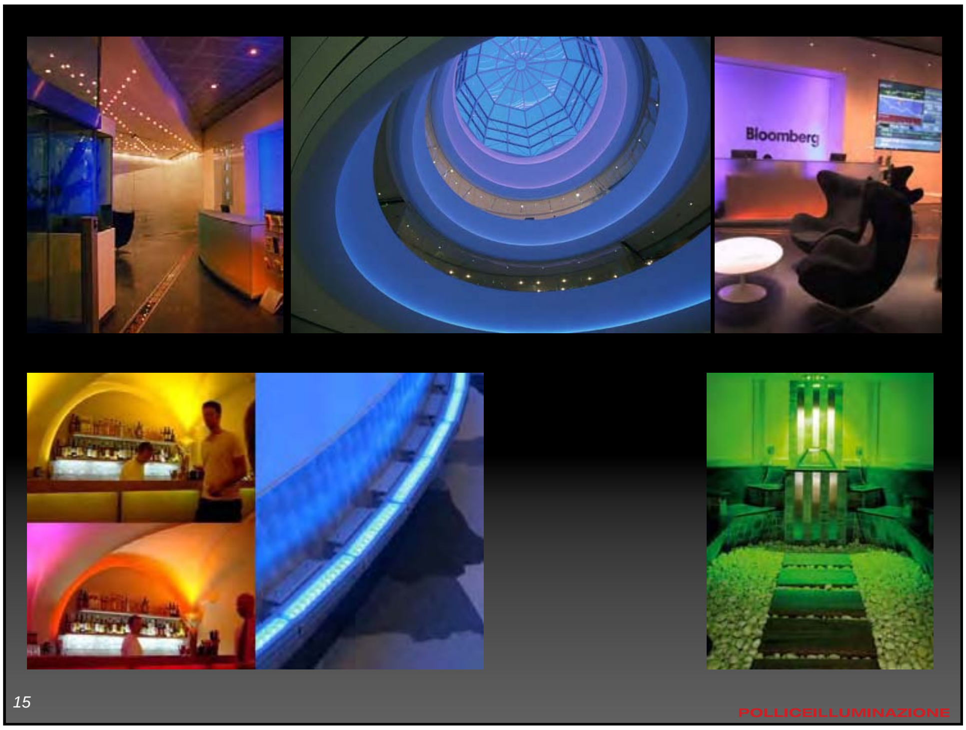
Metropolitan areas are always more planned as a scene set for events.

12

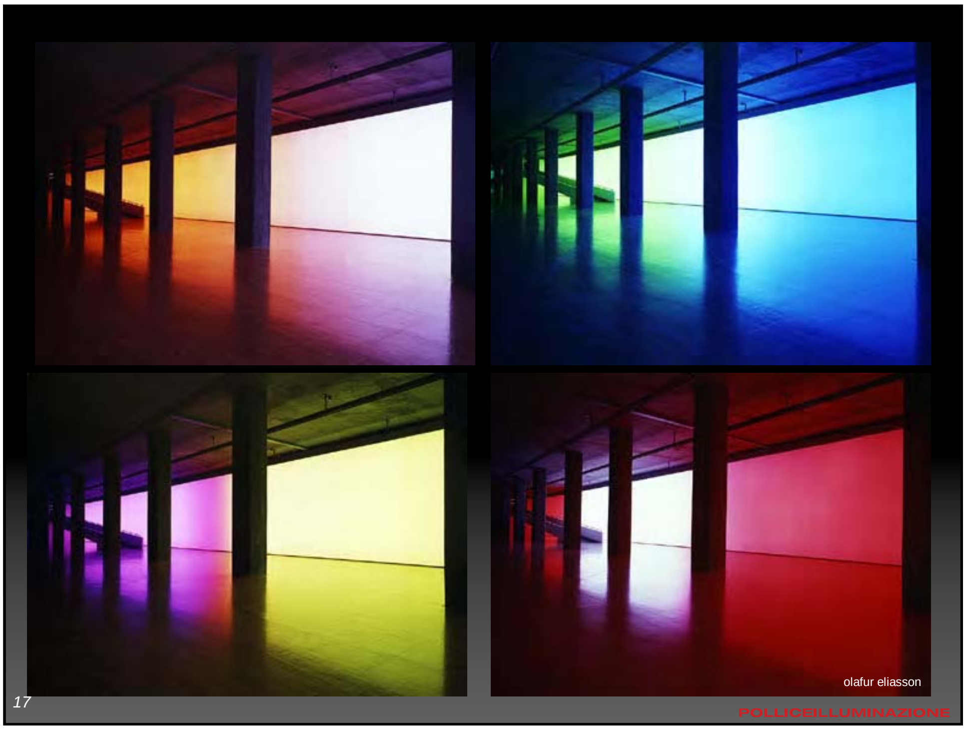
POLLICEILLUMINAZIONE

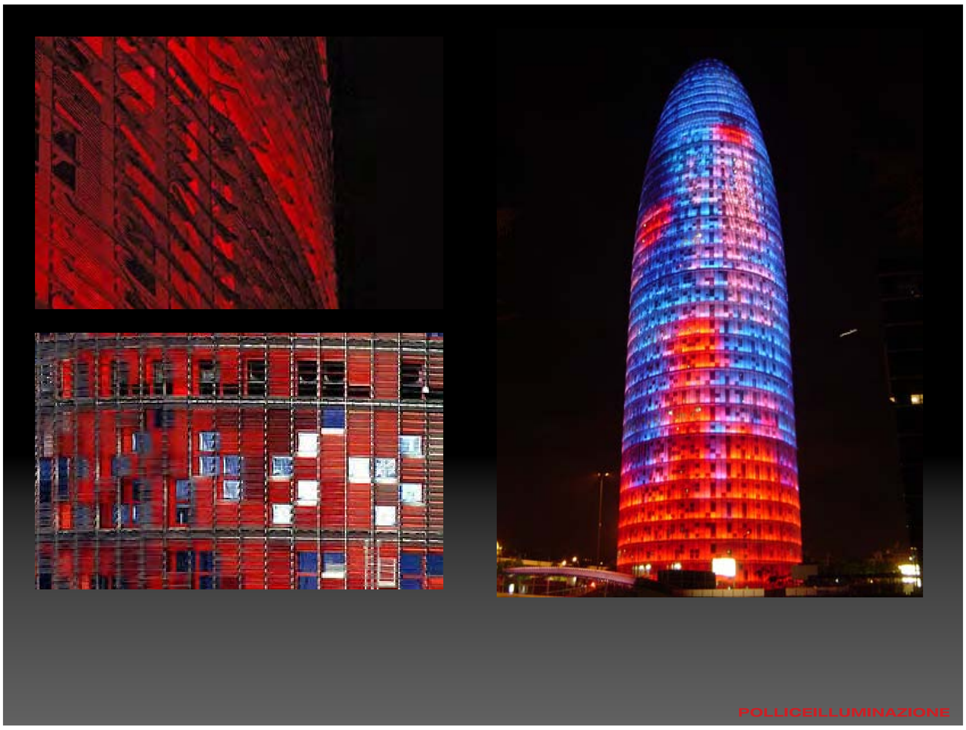

LEDs would have aroused the Kandinskij's enthusiasm
ignited Klee's fantasy and captivated futurists
13
POLLICEILLUMINAZIONE


Atelier of emotional exchange
14
POLLICEILLUMINAZIONE


Bloomberg
15
POLLICEILLUMINAZIONE


16
POLLICEILLUMINAZIONE


olafur eliasson
17
POLLICEILLUMINAZIONE


POLLICEILLUMINAZIONE

Light sets the stage for the concept of beauty.

18

POLLICEILLUMINAZIONE

The light of the woods is the most joyful.

(Piero Castiglioni, lighting designer)

LED is an energy ‘diamond’

SENSE OF LED Emotional lighting - Revelation of senses

19

POLLICEILLUMINAZIONE

SENSE OF LED

Emotional lighting
Vision of senses

Design of a wine cellar for Brunello di Montalcino

1 POLLICEILLUMINAZIONE

Architecture is made of light.

2 POLLICEILLUMINAZIONE

Light as an integral part of architecture; its beauty, function and form.

3

POLLICEILLUMINAZIONE

CONCEPT rendering

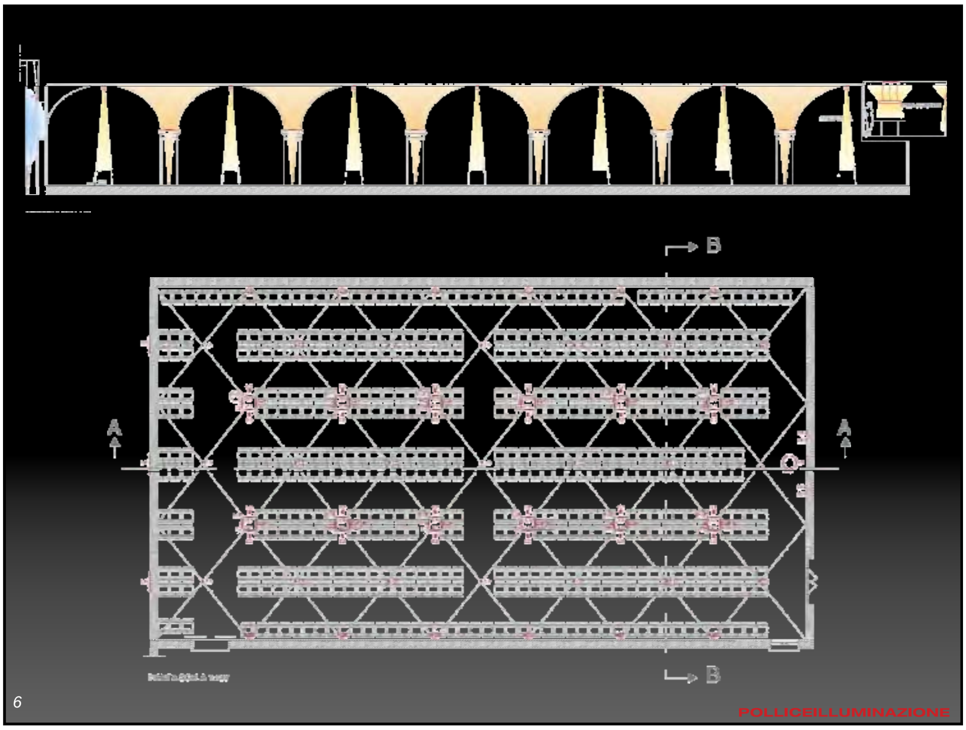
Picture of the present cellar

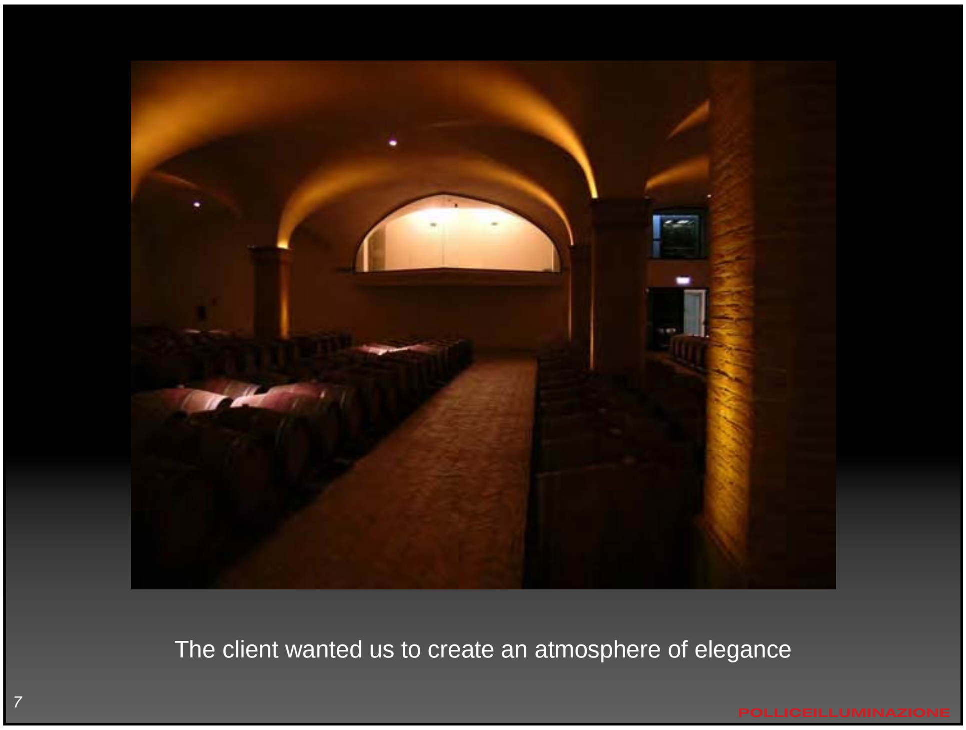
LED

4

POLLICEILLUMINAZIONE


5
POLLICEILLUMINAZIONE


B
A
A
B
6
POLLICEILLUMINAZIONE


The client wanted us to create an atmosphere of elegance
7
POLLICEILLUMINAZIONE

Session 4

Chair: Patricia Rizzo, Lighting Research Centre, Rensselaer Polytechnic Institute, US

Migrating from conventional sources to LEDs: findings of a lighting manufacturer.

****

Pio Nahum

Targetti Sankey S.p.A.

LED Workshop-ISPRA-May 2007

TARGETTI

LEDs are fantastic…

LED Workshop-ISPRA-May 2007

TARGETTI

LED manufacturers have made a great job during the last 2 years:

- Significant technical improvements, enabling LEDs to become a source suitable to illumination
- Powerful marketing, creating diffused awareness and interest on LEDs
- Effective lobbying, making the foundations for new international directives and new opportunities for the SSL industry

LED Workshop-ISPRA-May 2007 TARGETTI

TARGETTI GROUP ...

15000 + different products...

10 brands specialized in architectural lighting

Our focus is on "technical lighting" rather than decorative and residential

LED Workshop-ISPRA-May 2007

TARGETTI

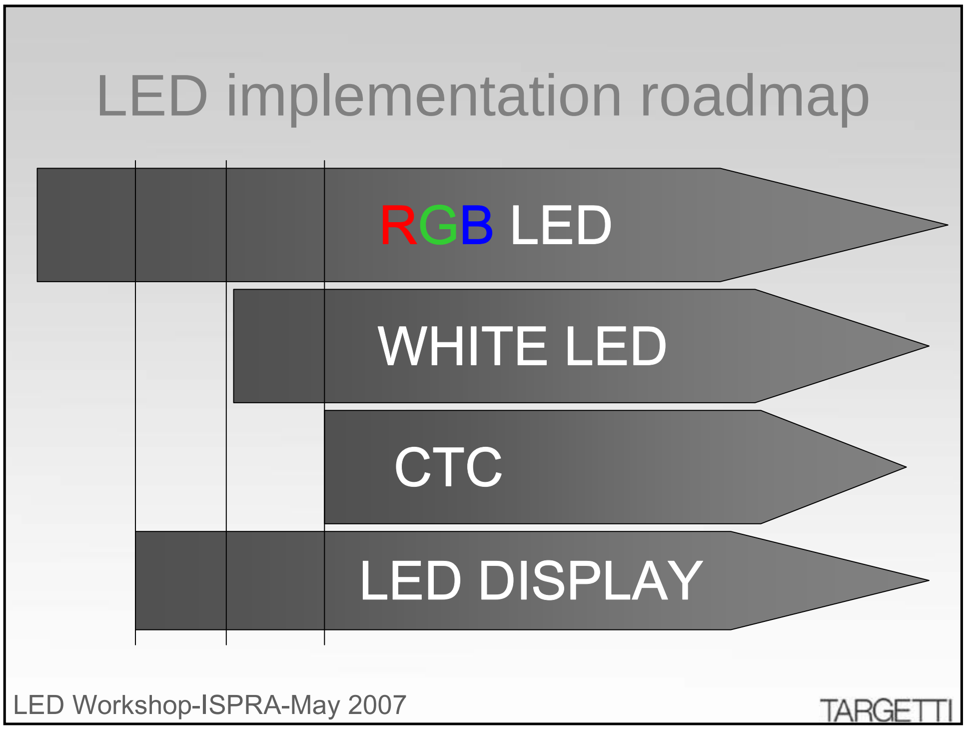
Advantages of LEDs (good-enough light output)

1. Compact size
2. Robust
3. Reduced maintenance costs (includes lifetime)
4. Control possibilities
5. Lack of radiated heat
6. Directional lighting
7. Low operating temperature
8. Low Voltage
9. Efficiency vs some conventional sources
10. Sustainability

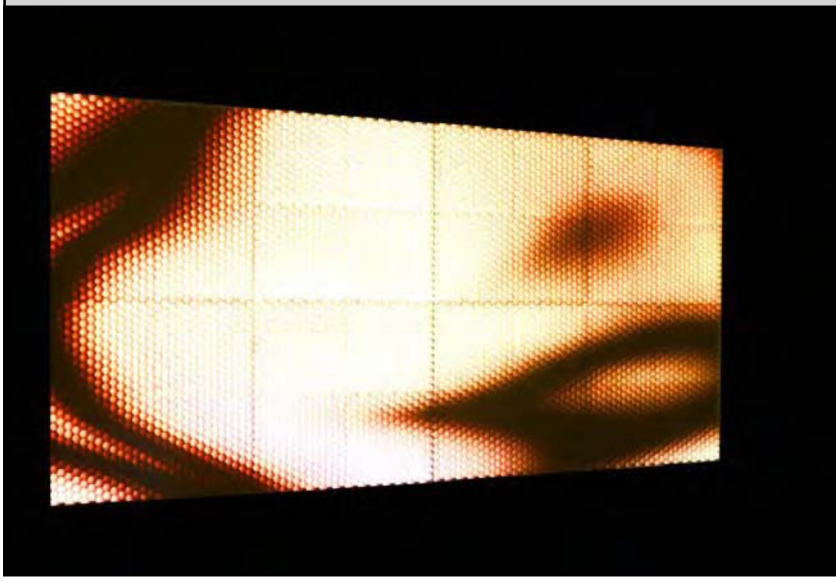
LED Workshop-ISPRA-May 2007

TARGETTI


Basketball Hall of Fame., USA
EXTERIEUR VERT


LED implementation roadmap
RGB LED
WHITE LED
CTC
LED DISPLAY
LED Workshop-ISPRA-May 2007
TARGETTI

LED digital display



WHY RGB LED?

- Emotional application (architainment)
  - Effect lighting
  - Mood lighting
  - Lack of consolidated standards
- Less stringent lighting criteria

LED Workshop-ISPRA-May 2007


LUCEVIVA
TARGETTI


Outdoor luminaires

Moving into White Light LED

LED Workshop-ISPRA-May 2007

TARGETTI

Since 1928 …

Culture of Light

LED Workshop-ISPRA-May 2007 TARGETTI

LED Workshop-ISPRA-May 2007 TARGETTI

LED in White Light applications (main issues)

- Realistic fixture performance
- Lack of standards
- Poor education of users
- CRI
- Control and electrical standards interfacing
- Consistency (binning)

LED Workshop-ISPRA-May 2007 TARGETTI

Challenges during design phase

- Need of in-house new specific expertise
- Different approach to design
  - Mechanical/electronic design fully integrated
- On-going electronics design during product life-cycle
- Outsourcing design of strategic components
  - weight of electronics value

LED Workshop-ISPRA-May 2007 TARGETTI

Challenges during design phase

- LED are not to be considered as a standard lighting source:
  - A conventional lighting fixture is designed to host a standard light source (interchangeable)
  - A LED luminaire is built “around” a LED

⇩

Partnership

LED Workshop-ISPRA-May 2007 TARGETTI

Challenges during manufacturing

- Procurement
  - New suppliers (different types of LEDs)
  - New logistics approach
- Manufacturing process and QC
- Outsourcing strategic components manufacturing (strict QC)
- Complex product manufacturing doc
- Product tracking (FW releases)

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Challenges in marketing

- Sales team education
- Customer education
- Need of complete lighting solution (including control and accessories)
- Conservative attitude of specifiers (lighting designers, architects)
  - Lack of knowledge
  - Mistrust on claimed performances and lifetime
  - Unclear economic advantage
- Ease of installation (comprehensive documentation and training tools)

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Conclusions

- LED technology for lighting still not mature
  - Efficacy (also in relation to system complexity)
  - Performance stability (temperature/lifetime)
  - Color (quality and consistency)

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TARGETTI

Conclusions

- Lighting manufacturers should use their expertise for creating more efficient and attractive final products:
  - Thermal management
  - Electrical optimization (driver)
  - Optical optimization (secondary optics)
  - Optimized “housing” design around LED miniaturized size
  - Deploy control versatility

LED Workshop-ISPRA-May 2007

TARGETTI

Conclusions

- LED manufacturers should learn architectural lighting language and criteria
- New standards should be developed
  - Photometrics for complete luminaires
  - Testing procedure
  - ……
- Consistent and realistic marketing
- Market education
- Sufficient life-cycle to ensure ROI

LED Workshop-ISPRA-May 2007

TARGETTI


Thanks for your attention!
LED Workshop-ISPRA-May 2007
TARGETTI

LUCE PLAN

may 2007

(LED, a new opportunity for design products)

(company)

_ Based in Milan, Luceplan is a market leader in the design lighting field. Avoiding the formal concerns and clichés, the company has made inventiveness, experimentation and beauty the cardinal points of its production

_ Extensive research work on model types, technology and on materials makes Luceplan one of the leaders in innovative lighting

_ The timeless light-weight shape of the products makes them a “contemporary classic” of Italian design

may 2007 www.luceplan.com

LUCE PLAN

(history)

_ 1939: Gino Sarfatti, pioneer of Italian contemporary lighting, founds **Arteluce**

_ 1978: his son Riccardo together with his wife Sandra Severi and his friend Paolo Rizzatto creates **Luceplan**

_ 1984: Alberto Meda, an engineer and specialist in plastics, joined the group of founding partners

may 2007 www.luceplan.com

(company)

Luceplan S.p.A.
Milan
(1978)

Luceplan USA
New York
(1994)

Luceplan Germany
Berlin
(1995)

Luceplan France
Paris
(2003)

Luceplan Scandinavia
Copenhagen
(2004)

may 2007 www.luceplan.com

(company)

- _ Turnover 2006: € 22.000.000
- _ Employees: 100 worldwide
- _ Research and development investments: 4,5% of total turnover
- _ Exports: 75% of turnover
- _ Major export countries: Europe, USA, China, Japan, Australia

may 2007 www.luceplan.com LUCE PLAN

(awards)

Compasso d'Oro Prize

European Community Design Prize 1994

DESIGN PLUS

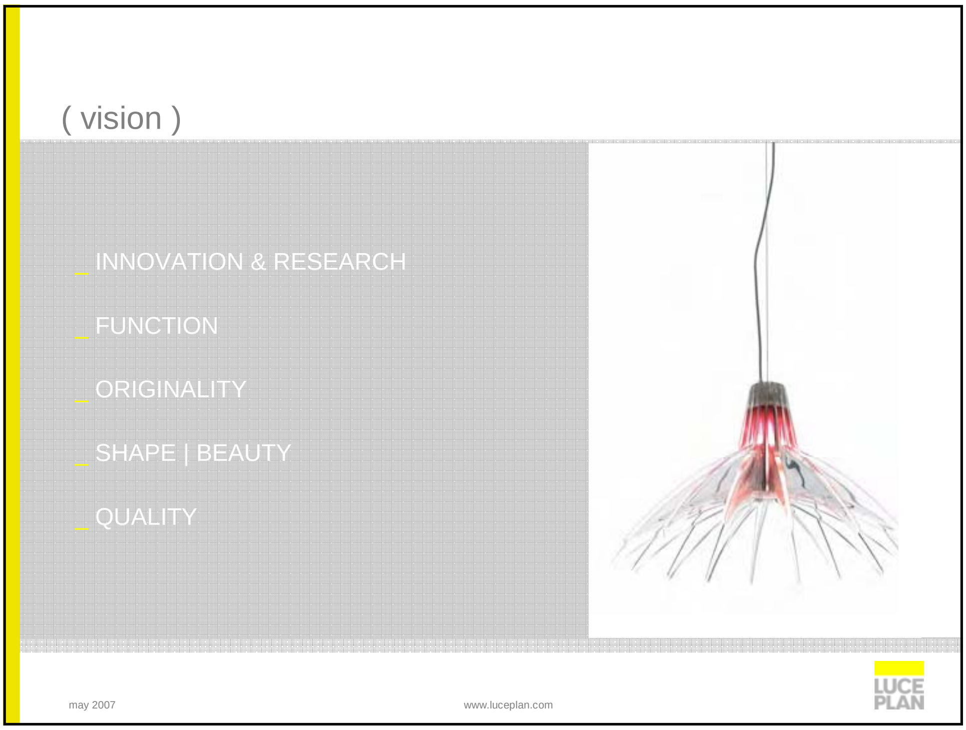
Good Design

Lights of the Future
European Design Competition

Premio all'Innovazione Amica dell'Ambiente

_ Its special approach to the project has won Luceplan many acknowledgements given by the most prestigious institutions in the scene of design.

may 2007 www.luceplan.com LUCE PLAN


(vision)
_ INNOVATION & RESEARCH
_ FUNCTION
_ ORIGINALITY
_ SHAPE | BEAUTY
_ QUALITY
may 2007
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(icons)
may 2007
www.luceplan.com
LUCE PLAN


(costanza _ 1986)
UPDATING THE ARCHETYPAL
LAMP-WITH-THE-SHADE CONCEPT
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(costanza _ 1986)
may 2007
www.luceplan.com
LUCE PLAN

(lola _ 1987)

RESEARCH ON MATERIALS

_ design: A. Meda, P. Rizzatto
_ telescopic carbon fibre
_ articulated tripod base
_ touch sensor dimmer
_ Compasso d'Oro Award

may 2007 www.luceplan.com LUCE PLAN

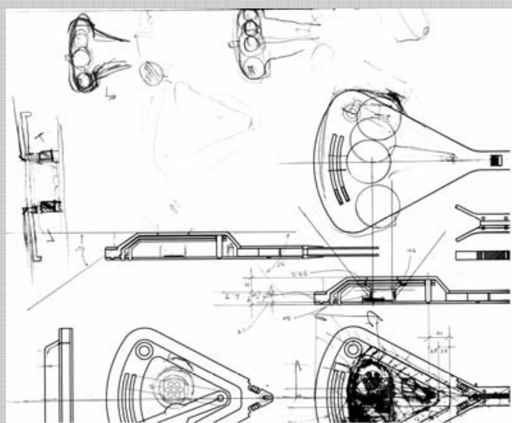
(new opportunities from LED technology)

_ FREEDOM OF MOVEMENT

_ ENERGY SAVING

_ REDUCED DIMENSIONS

_ IMPROVING STANDARD PERFORMANCES

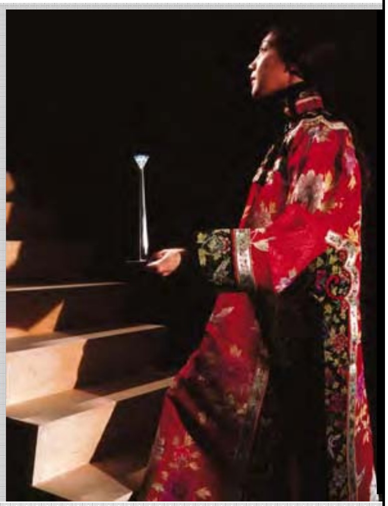


may 2007 www.luceplan.com LUCE PLAN

(starled light _ 2001)

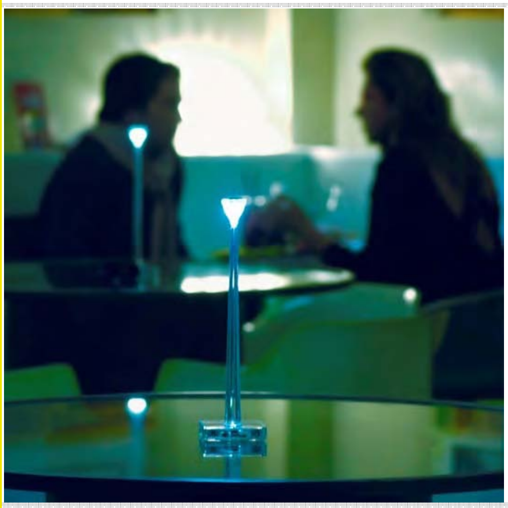
FREEDOM OF MOVEMENT

_ design: A. Meda, P. Rizzatto
_ wireless and weightless
_ 1 watt efficiency LED
_ rechargeable batteries



may 2007 www.luceplan.com LUCE PLAN

(starled light _ 2001)



may 2007 www.luceplan.com LUCE PLAN

(solar bud _ 1998)

ENERGY SAVING

_ design: Ross Lovegrove
_ solar energy
_ silicon photovoltaic cells
_ 3 white LED
_ light durability: 13 hours
_ no wiring costs

may 2007 www.luceplan.com LUCE PLAN

(solar bud _ 1998)

may 2007 www.luceplan.com LUCE PLAN

(sky _ 2007)

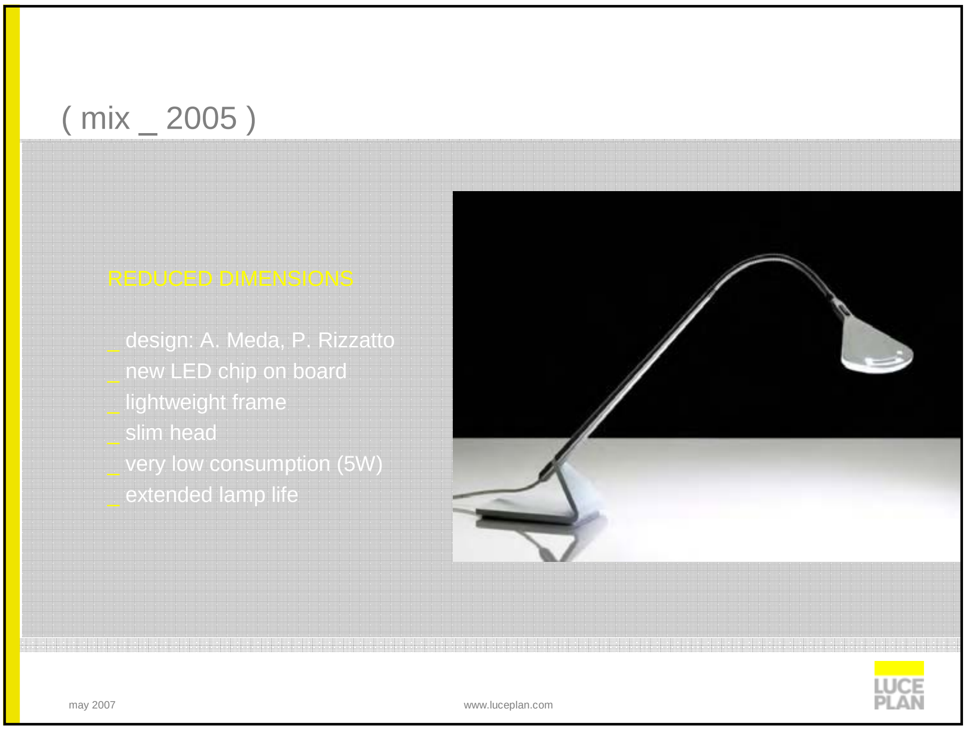
ENERGY SAVING

_ design: A. Häberli
_ outdoor system
_ photovoltaic LED version
_ solar energy
_ zero consumption
_ no wiring costs

may 2007 www.luceplan.com LUCE PLAN

(sky _ 2007)

may 2007 www.luceplan.com LUCE PLAN


(mix _ 2005)
REDUCED DIMENSIONS
_ design: A. Meda, P. Rizzatto
_ new LED chip on board
_ lightweight frame
_ slim head
_ very low consumption (5W)
_ extended lamp life
may 2007
www.luceplan.com
LUCE PLAN


(mix_2005)
Lights of the Future 2006
European Design Competition
DESIGN PLUS
may 2007
www.luceplan.com
LUCE PLAN

(berenice LED _ 2007)

IMPROVING STANDARD PERFORMANCES

_ design: A. Meda, P. Rizzatto
_ original model in 1985
_ new LED 10W source
_ low consumption
_ New York Times building

may 2007 www.luceplan.com LUCE PLAN

(berenice LED _ 1985 / 2007)

may 2007 www.luceplan.com LUCE PLAN

NORD LIGHT

ledco

RGB SYSTEM

YOUR PERSONAL LIGHTING

Bernd Bueno, RGB Chief Engineer

Marco Michelini, Ph.D., Export Manager

Overview

- Company Introduction
- Our perspective on LED advantages
- Applications of LEDs in projects
- Questions?

Nord Light s.p.a.

- Italian company, based in Sieci – Florence
- In LED market since 1997
- Your personal lighting: focus on direct cooperation with lighting consultants, architects, engineers to deliver projects
- Internal lab to design circuits, components, systems
- Internal crew to design light fittings
- Focus on follow up with clients to solve any issue
- Peculiar care in post-sale operation

LED Advantages

Economic advantages

- Low energy consumption (reduction in on-site energy costs)
- Low heat development (thumbs up for clothing, paintings, museums)
- Reduction of air conditioning costs (reduction in absorbed power, nice!)
- Almost unlimited lifespan of the lamp
- No maintenance costs (will help in paying the starting price for LED)
- No cleaning costs (reduction of fixed costs)
- Less transport cost
- Less disposal cost

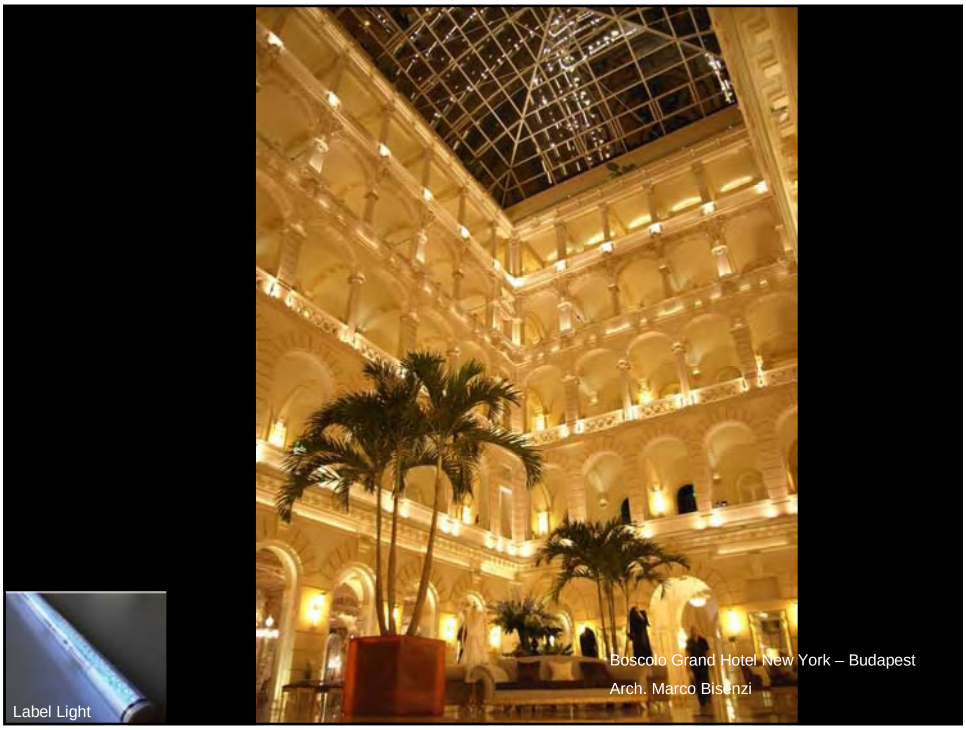
Many other advantages have been already addressed by speakers during this workshop

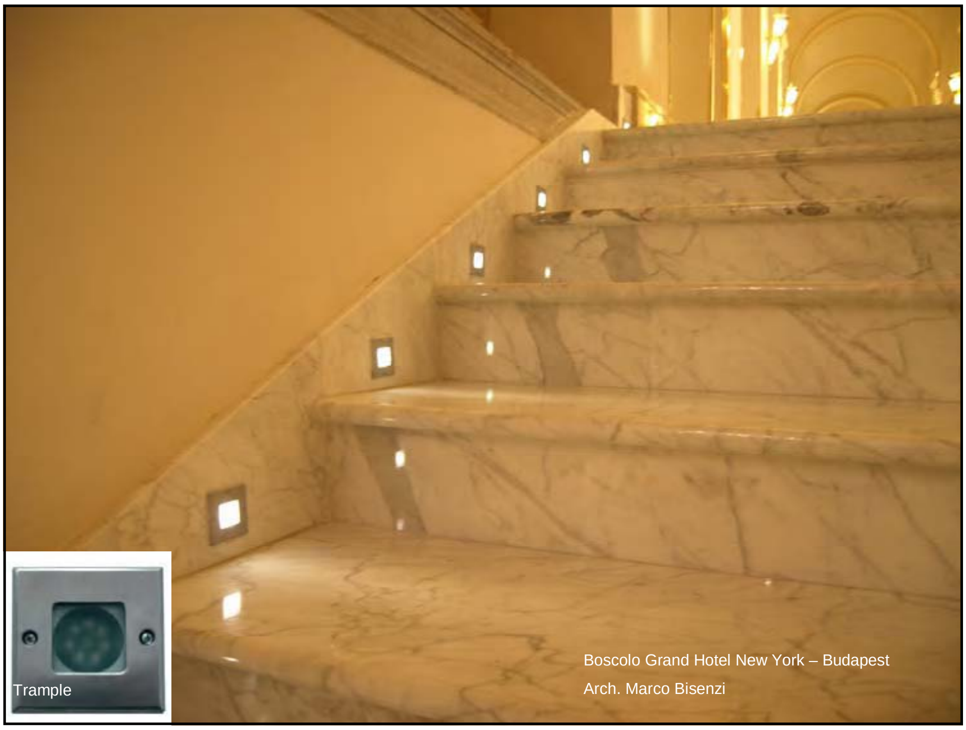
LED Advantages

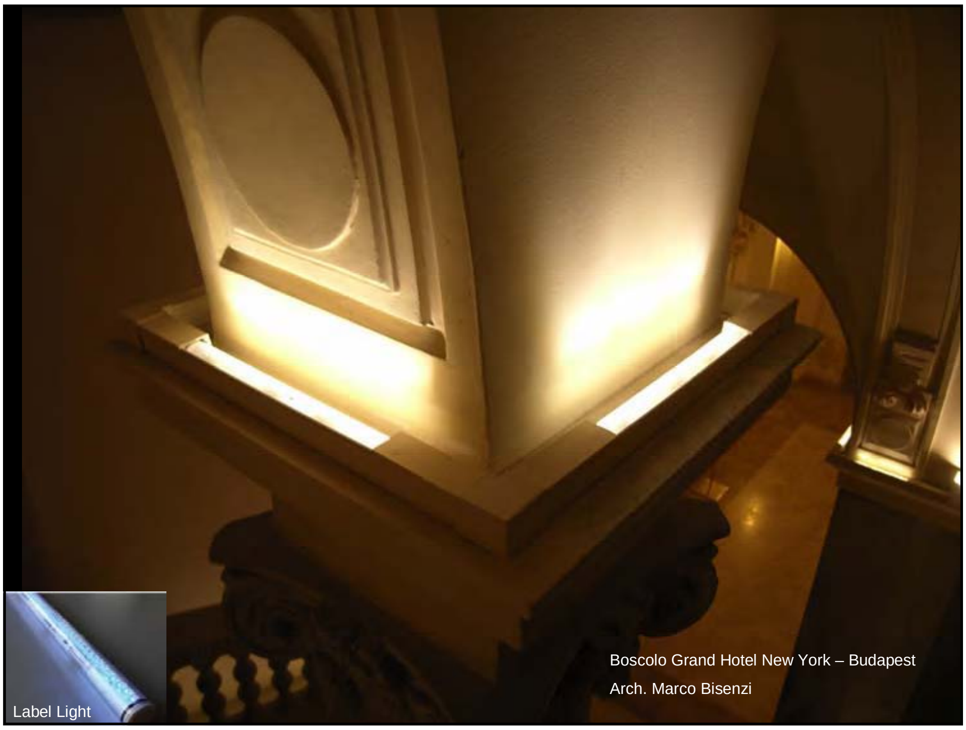
Design advantages:
- Small design
- Small dimension
- Can fit in conventional light fittings
- Dimming is possible without change in color temperature
- Color of light is adjustable (with use of multi-colored LEDS)

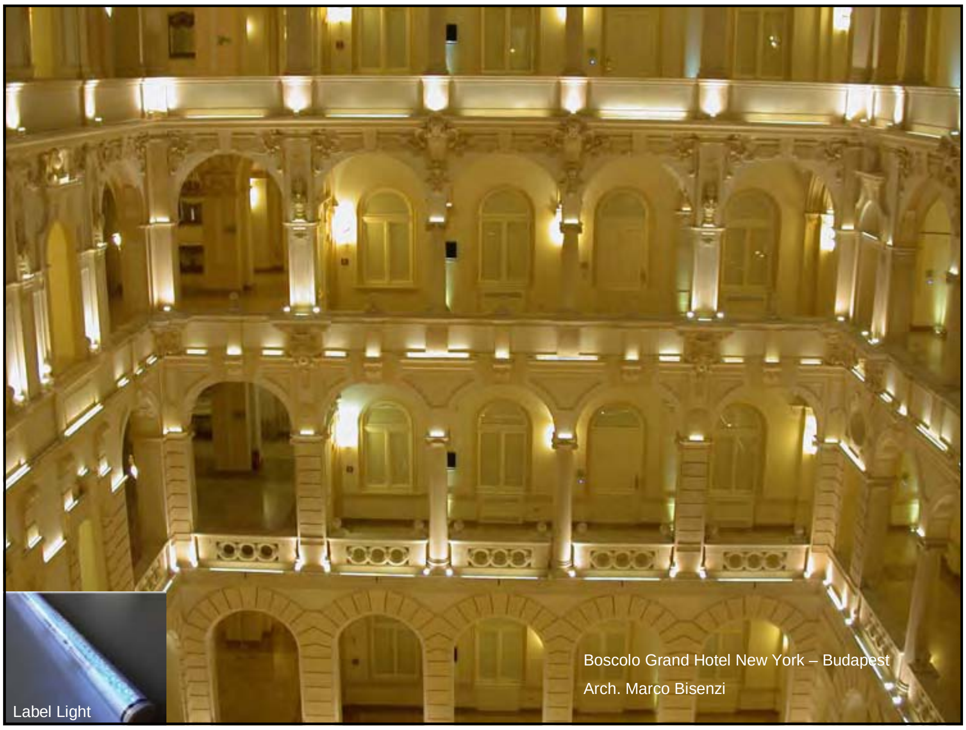
Environmental advantages:
- Minimal use of resources
- Low power requirement
- Does not provoke harm to insects and does not disturb insect orientation

SOME PRACTICAL EXAMPLES


Label Light
Boscolo Grand Hotel New York – Budapest
Arch. Marco Bisenzi


Trample
Boscolo Grand Hotel New York – Budapest
Arch. Marco Bisenzi


Label Light
Boscolo Grand Hotel New York – Budapest
Arch. Marco Bisenzi


Label Light
Boscolo Grand Hotel New York – Budapest
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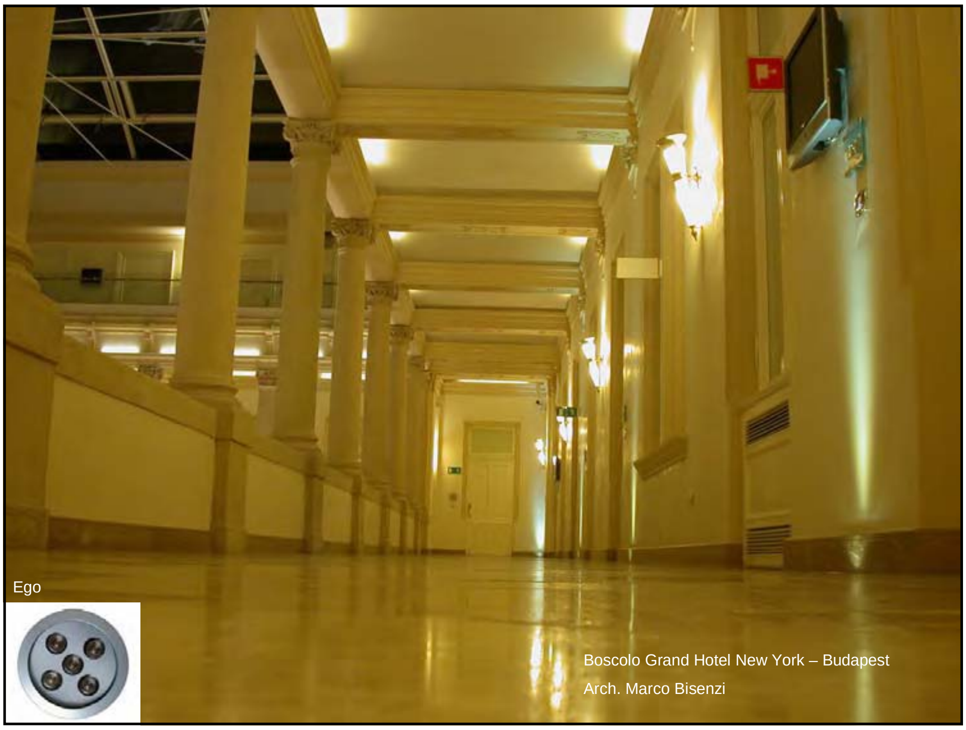
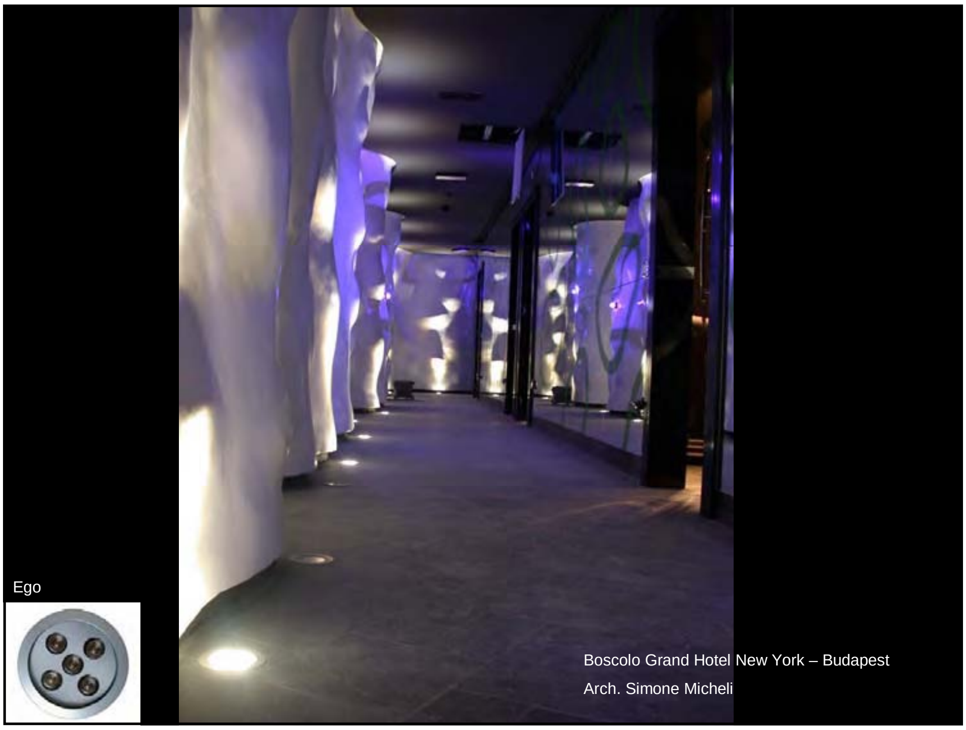
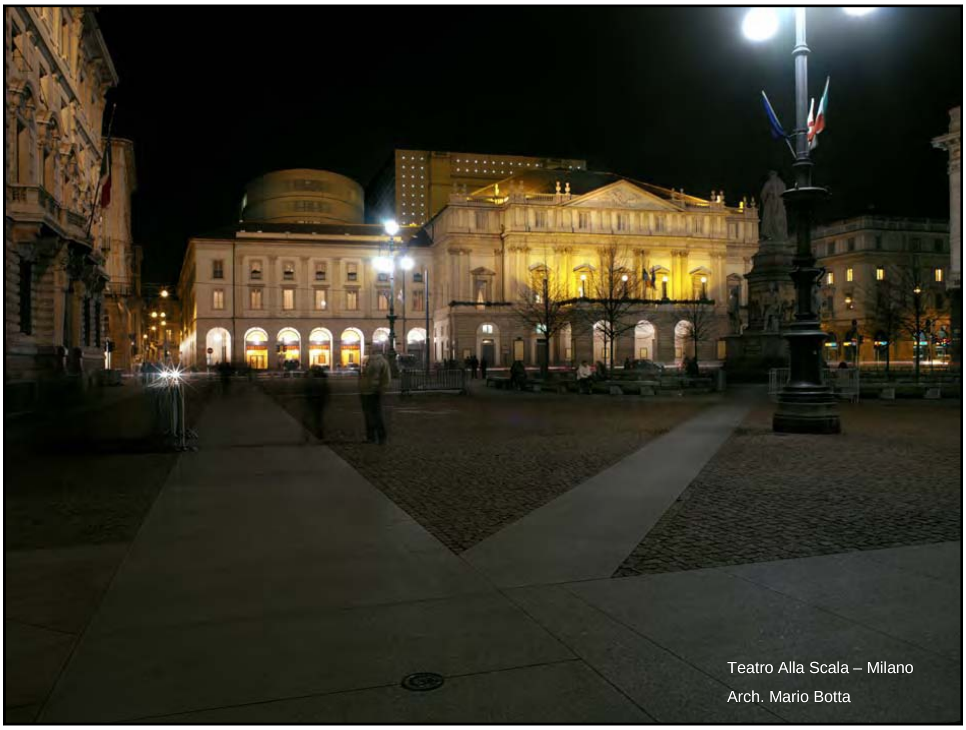
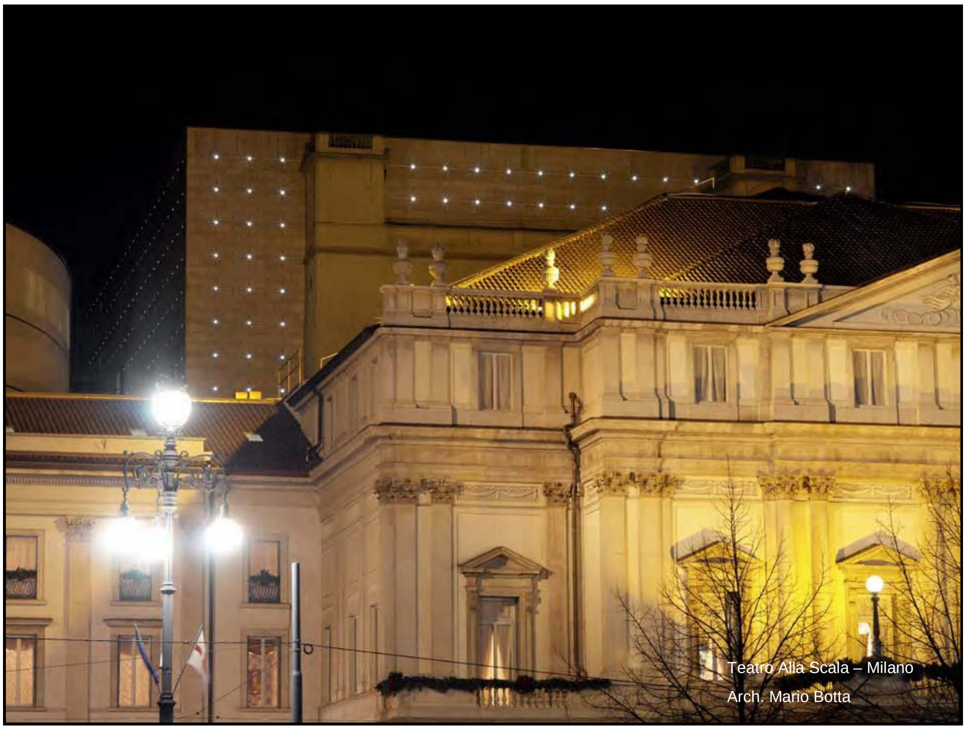

Ego
Boscolo Grand Hotel New York – Budapest
Arch. Marco Bisenzi


Ego
Boscolo Grand Hotel New York – Budapest
Arch. Simone Micheli


Teatro Alla Scala – Milano
Arch. Mario Botta


Teatro Alla Scala – Milano
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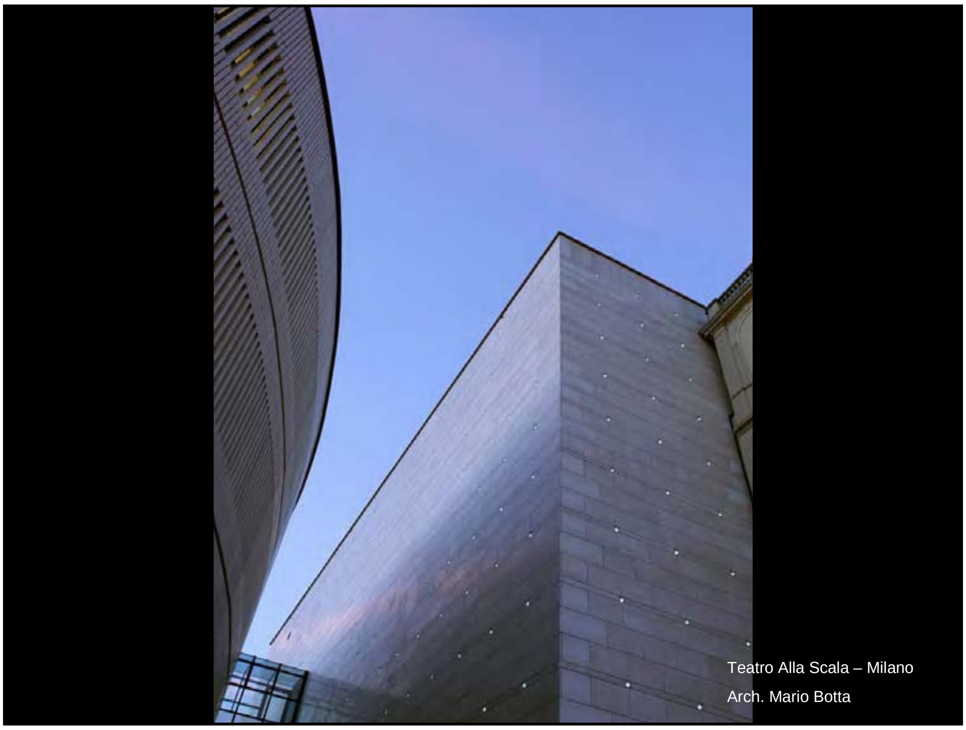
Teatro Alla Scala – Milano
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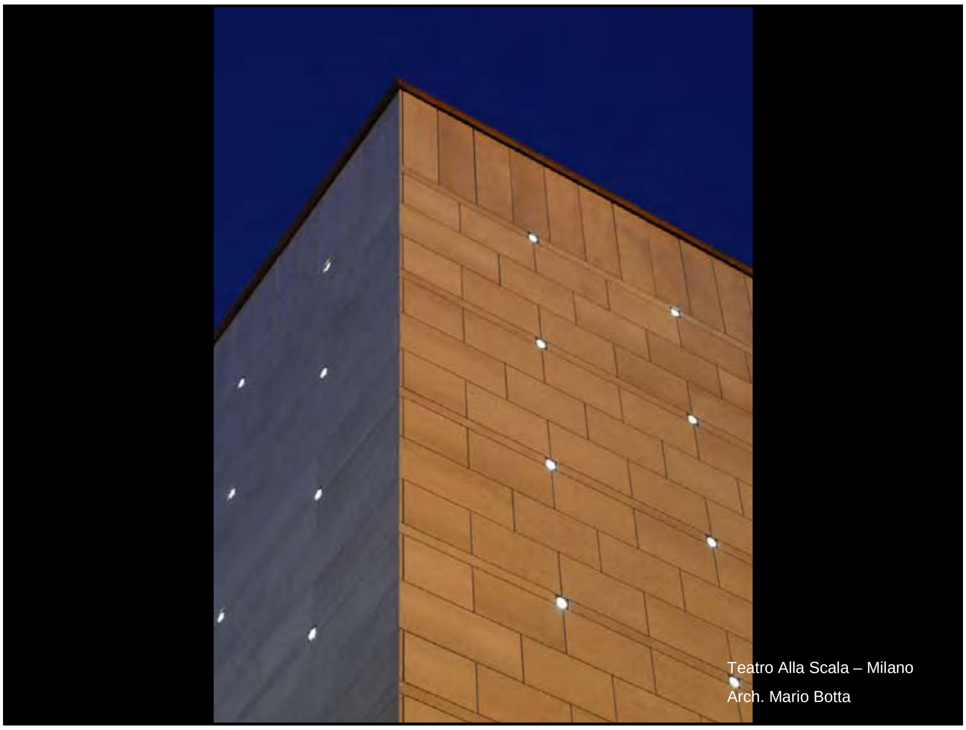
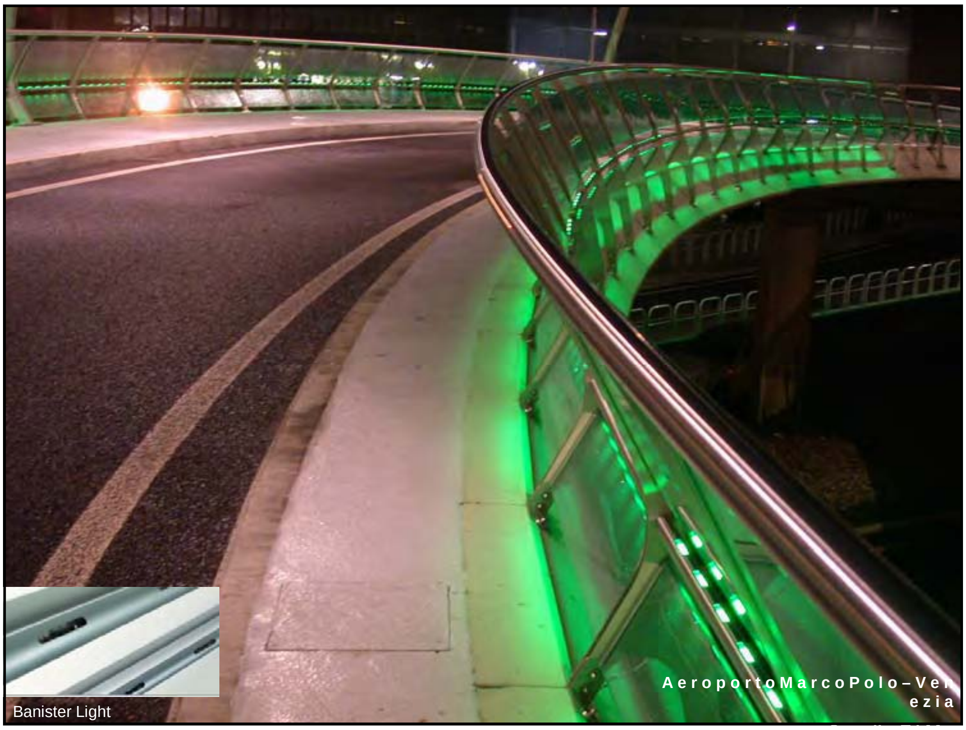

Teatro Alla Scala – Milano
Arch. Mario Botta

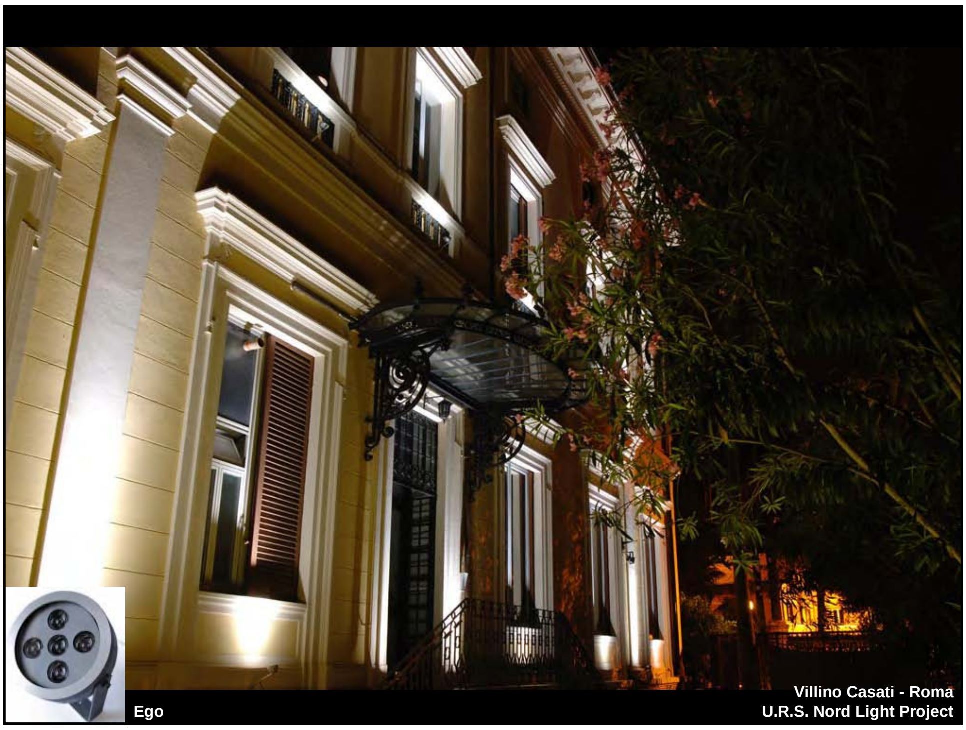

Teatro Alla Scala – Milano
Arch. Mario Botta


Banister Light
A e r o p o r t o M a r c o P o l o – V e n e z i a

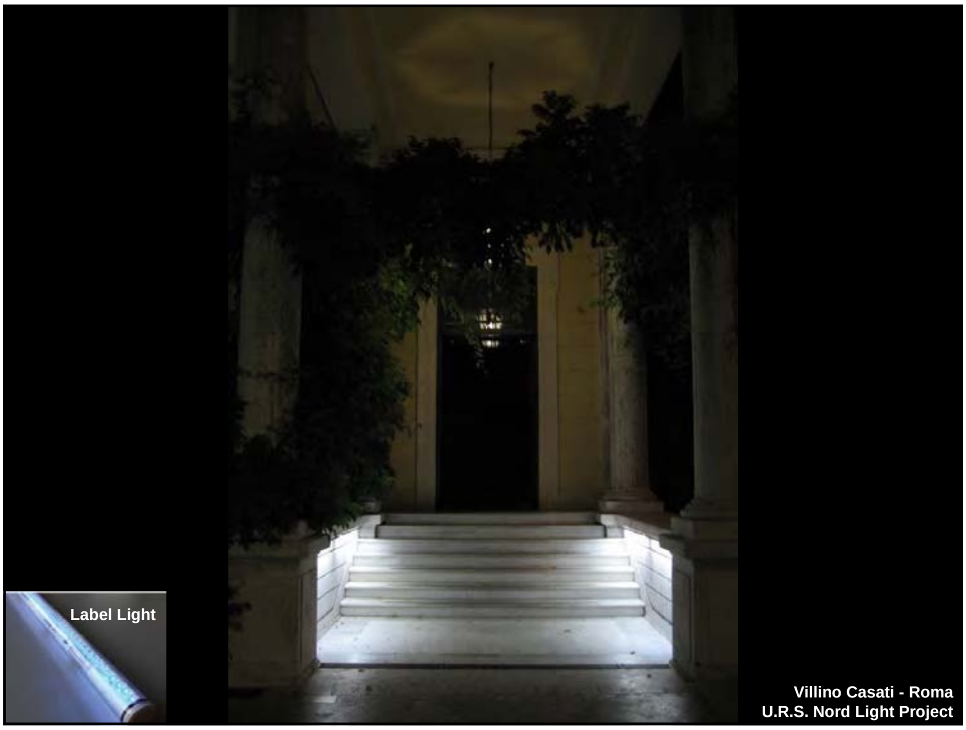

Banister Light
A e r o p o r t o M a r c o P o l o – V e n e z i a


Banister Light
A e r o p o r t o M a r c o P o l o – V e n
e z i a


Label Light
Ego
Villino Casati - Roma
U.R.S. Nord Light Project

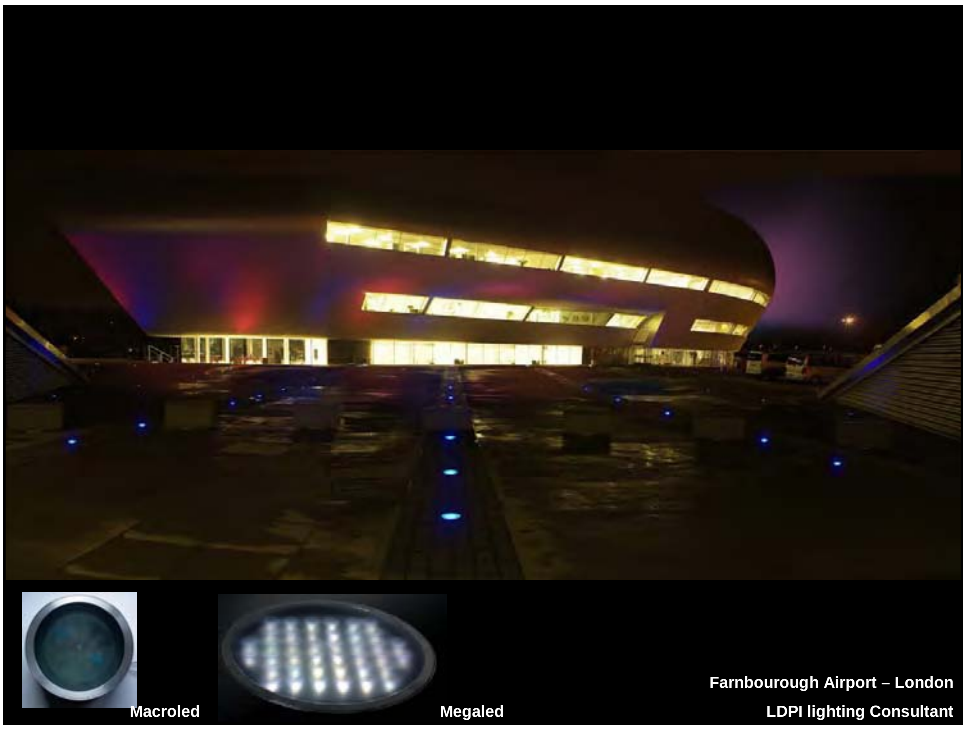

Ego
Villino Casati - Roma
U.R.S. Nord Light Project

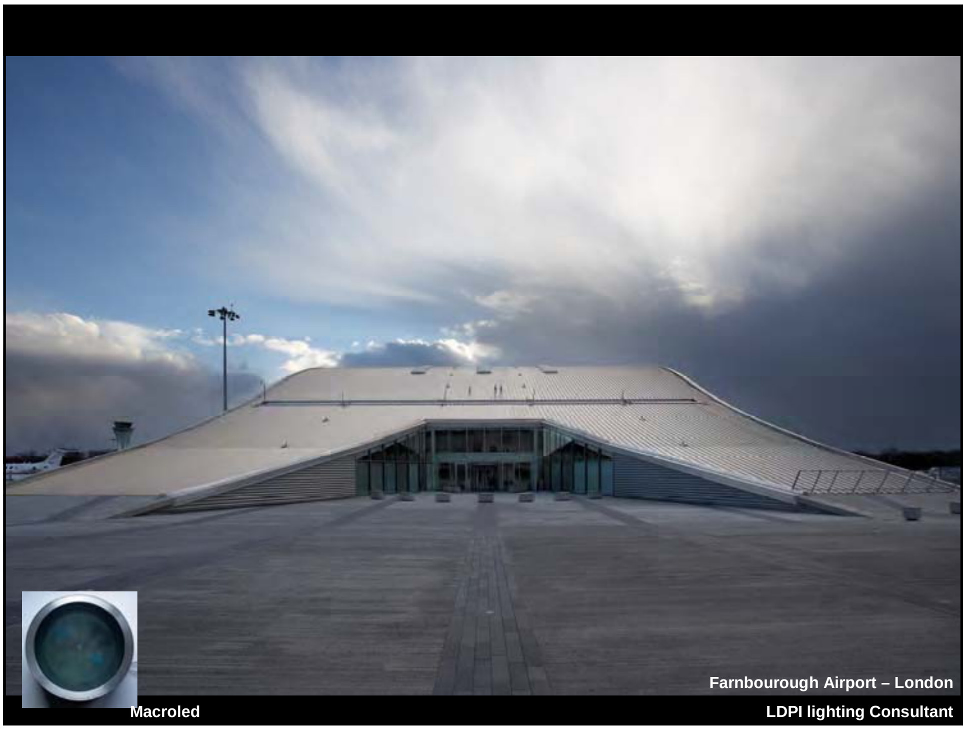

Label Light
Ego
Villino Casati - Roma
U.R.S. Nord Light Project


Label Light
Villino Casati - Roma
U.R.S. Nord Light Project


Riga
Piazza dei guidi – vinci (fi)
Studio arch. cannata

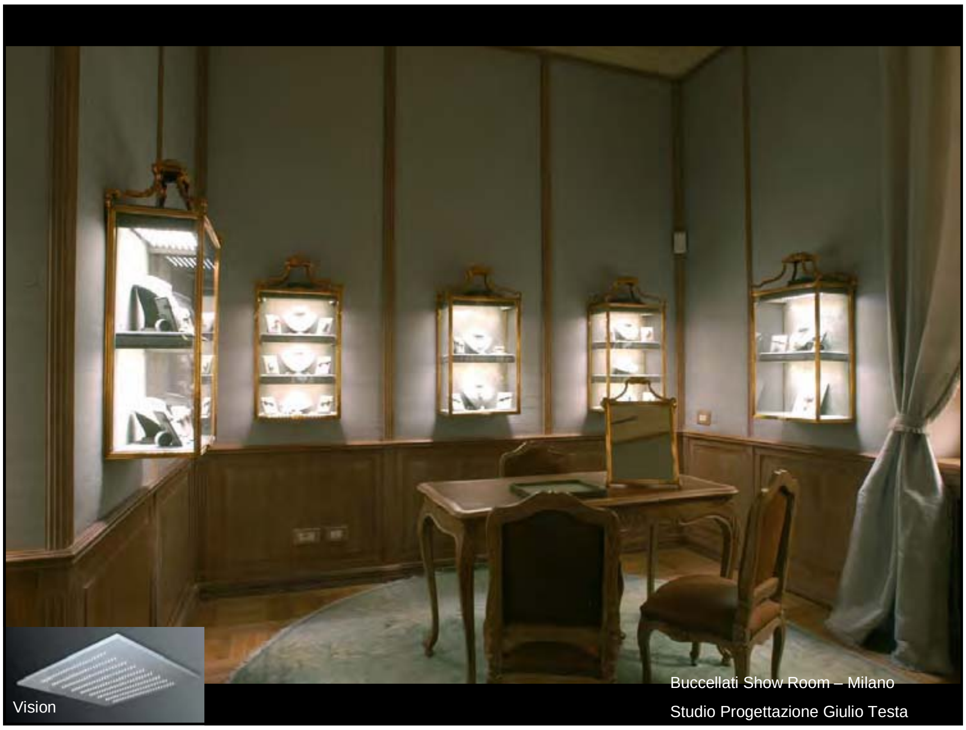

Riga
Piazza dei guidi – vinci (fi)
Studio arch. cannata

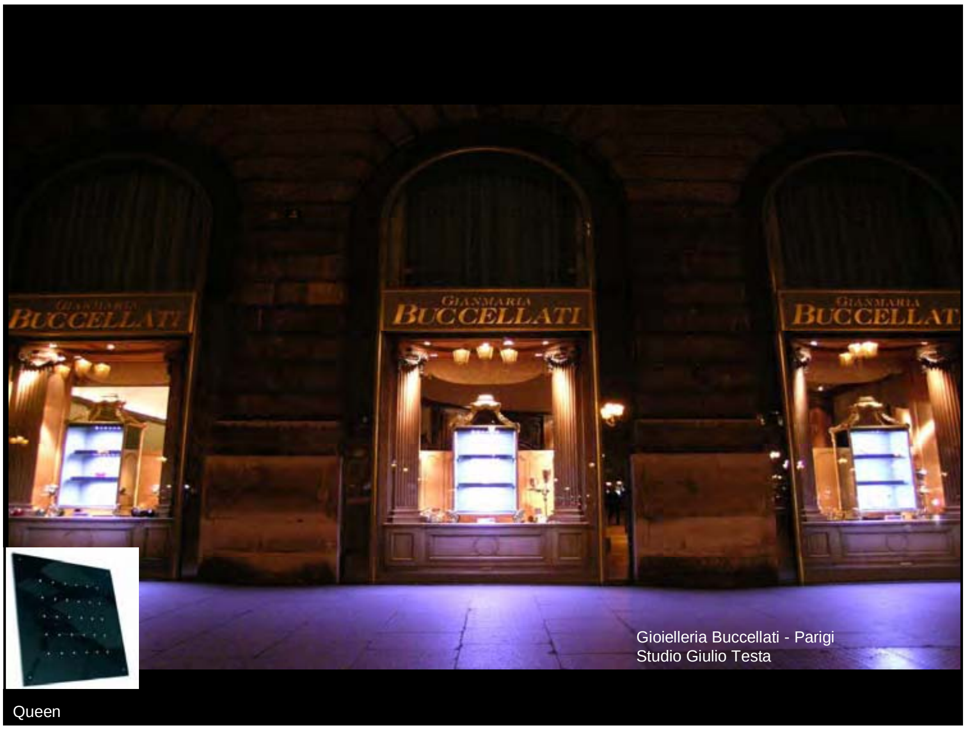

Macroled
Megaled
Farnbourough Airport – London
LDPI lighting Consultant

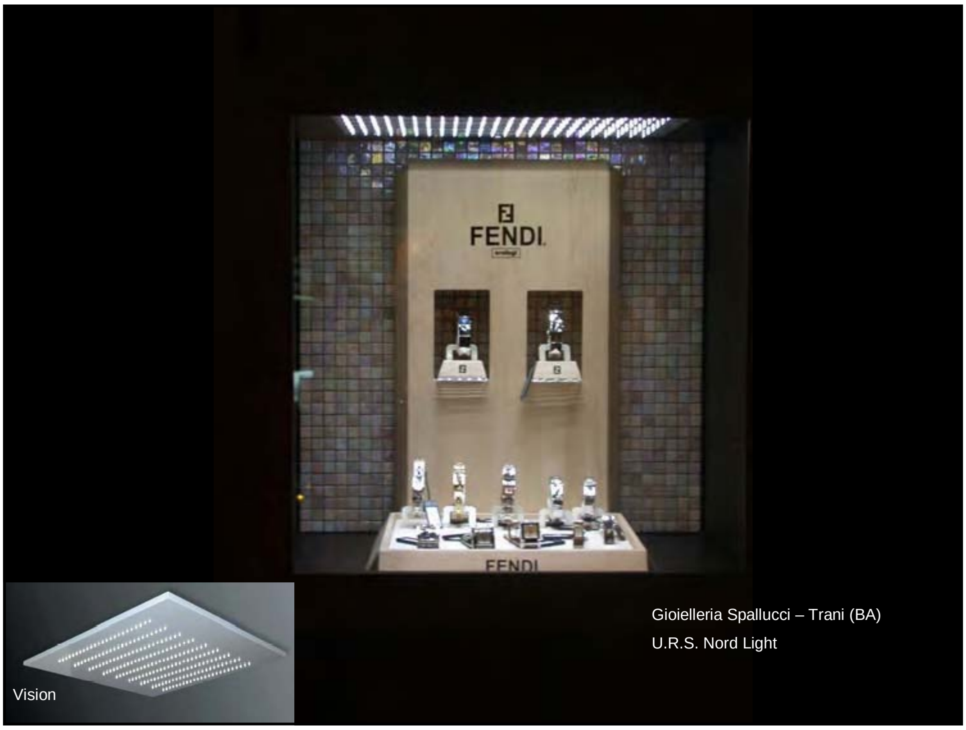

Farnbourough Airport – London
Macroled
LDPI lighting Consultant


Farnbourough Airport – London
Macroled
Megaled
LDPI lighting Consultant


Vision
Buccellati Show Room – Milano
Studio Progettazione Giulio Testa


Vision
Buccellati Show Room – Milano
Studio Progettazione Giulio Testa


GIANMARIA
BUCCELLATI
Gioielleria Buccellati - Parigi
Studio Giulio Testa
Queen


FENDI
Gioielleria Spallucci – Trani (BA)
U.R.S. Nord Light
Vision

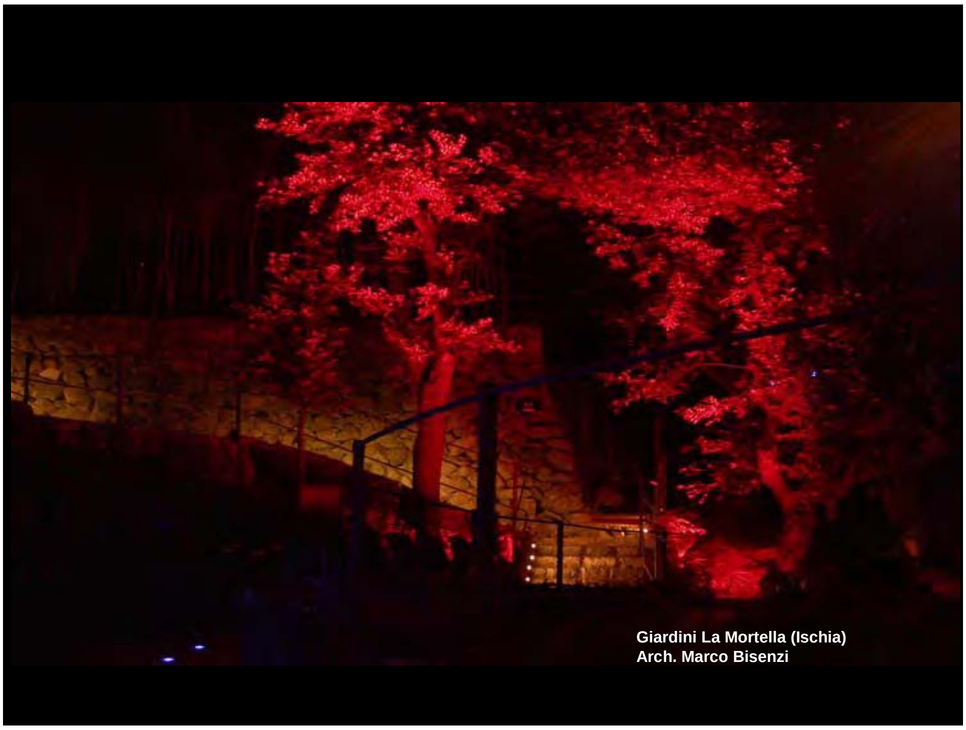

Vision
Gioielleria Spallucci – Trani (BA)


ELMO
Giardini La Mortella (Ischia)
Arch. Marco Bisenzi


Giardini La Mortella (Ischia)
Arch. Marco Bisenzi

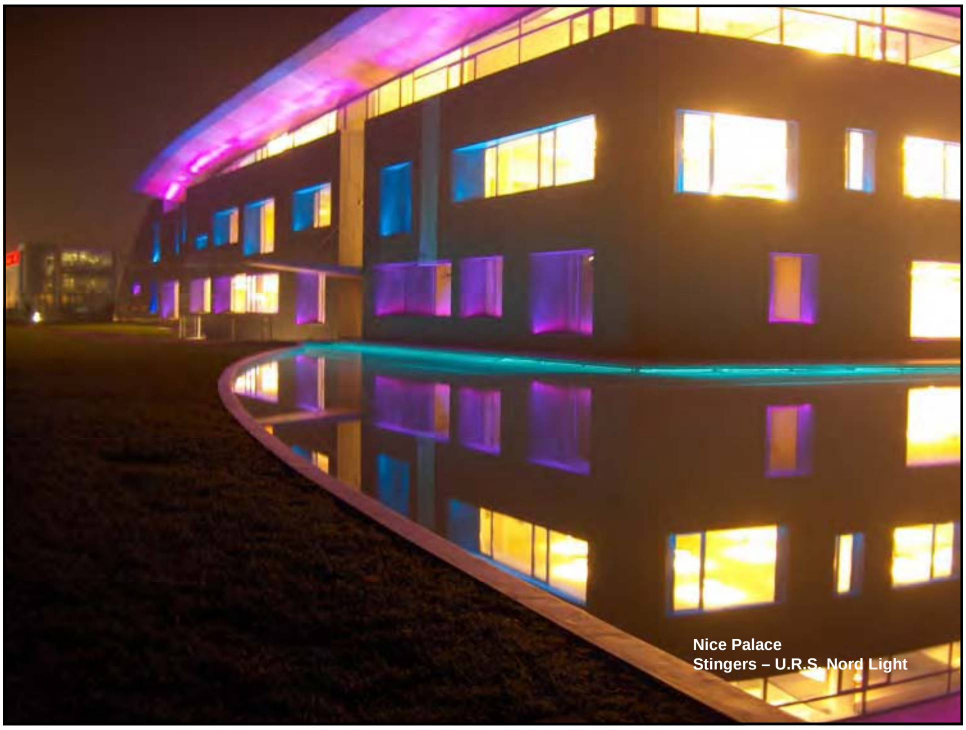

Giardini La Mortella (Ischia)
Arch. Marco Bisenzi


Giardini La Mortella (Ischia)
Arch. Marco Bisenzi

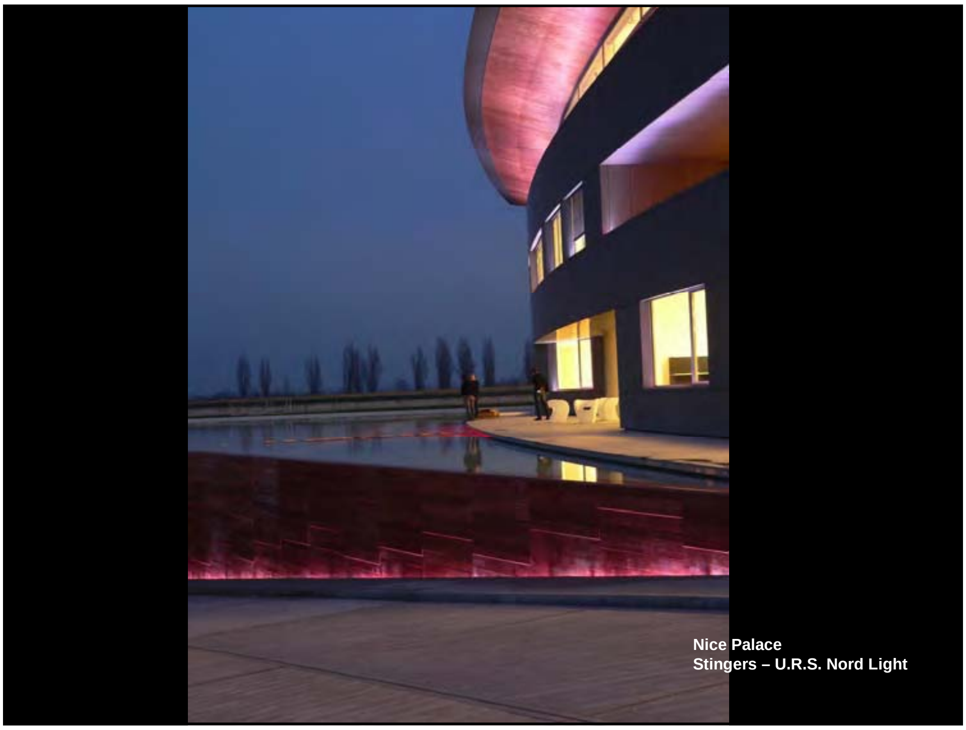

Giardini La Mortella (Ischia)
Arch. Marco Bisenzi


Giardini La Mortella (Ischia)
Arch. Marco Bisenzi


Giardini La Mortella (Ischia)
Arch. Marco Bisenzi


Nice Palace
Stingers – U.R.S. Nord Light


Nice Palace
Stingers – U.R.S. Nord Light


Nice Palace
Stingers – U.R.S. Nord Light


Nice Palace
Stingers – U.R.S. Nord Light

Conclusions

LED is not yet (nor will it be?) able to replace traditional light

LED can be gently melted together with traditional light in projects

LED fittings have to be carefully planned before installations or they will lose their appeal and potential

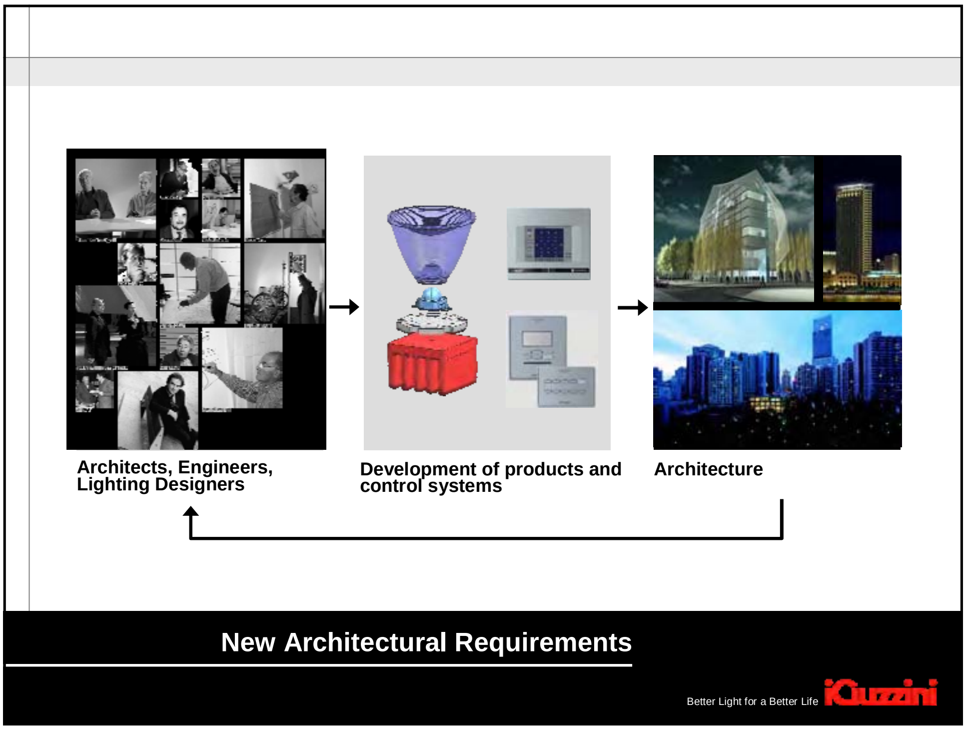
LED can significantly help in reducing power consumption in projects when correctly used

Thank you for the attention

More info: www.nordlight.eu
b.bueno@nordlight.it
m.michelini@nordlight.it

QUESTIONS?


iGuzzini Partner for…
New Architectural Requirements
Research and Solutions
Better Light for a Better Life
iGuzzini


Architects, Engineers, Lighting Designers
Development of products and control systems
Architecture
New Architectural Requirements
Better Light for a Better Life
iGuzzini

Architects, Engineers, Lighting Designers

Development of products and control systems

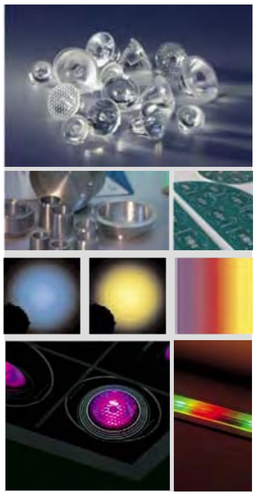
Architecture

New Architectural Requirements

Better Light for a Better Life iGuzzini

Main Advantages

- Very compact dimensions of lighting fixtures
- Dynamic colour control (RGB multichip LEDs, individually controlled) and high colour saturation
- Large range of colour temperatures
- Long operating life
- Resistance
- No maintenance costs
- Higher luminous efficiency
- Clean light without IR and UV
- Safety, because of very low voltage
- Very reduced amount of heat (no risks of burns)
- Cold switch-on (– 40°C), solid configuration non sensitive to cold temperatures
- Direct exact luminous emission without accessories or refractors
- Use of efficient optics made of technopolymers
- - CO_2



Why LEDs?

Better Light for a Better Life iGuzzini

- CO_2: for an ethics of Light according to iGuzzini illuminazione

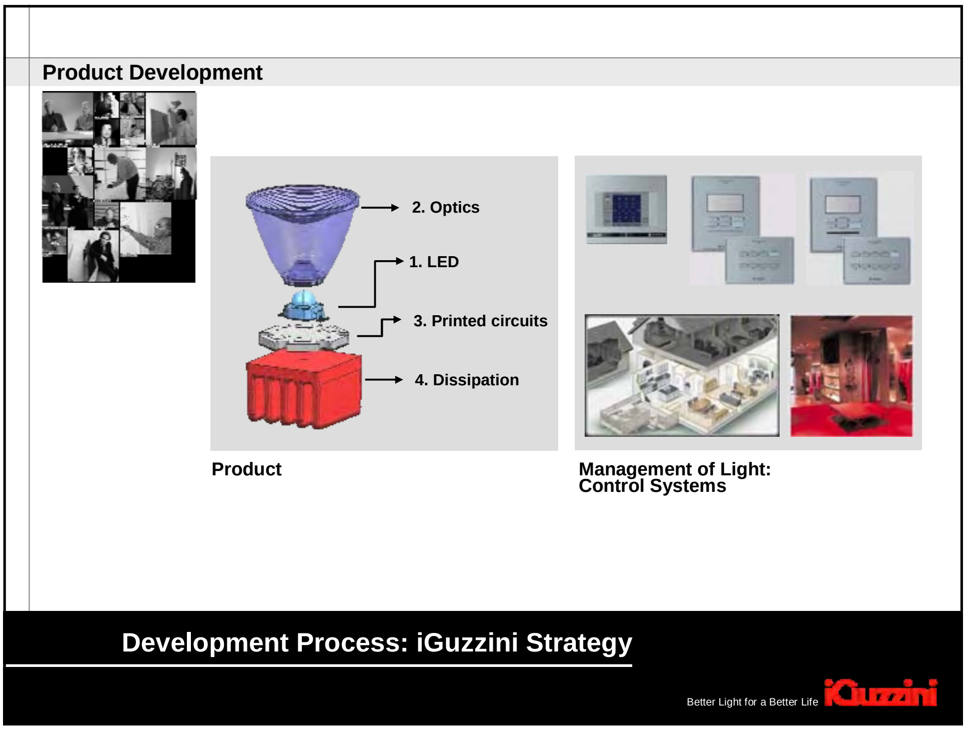
Euroluce 2007

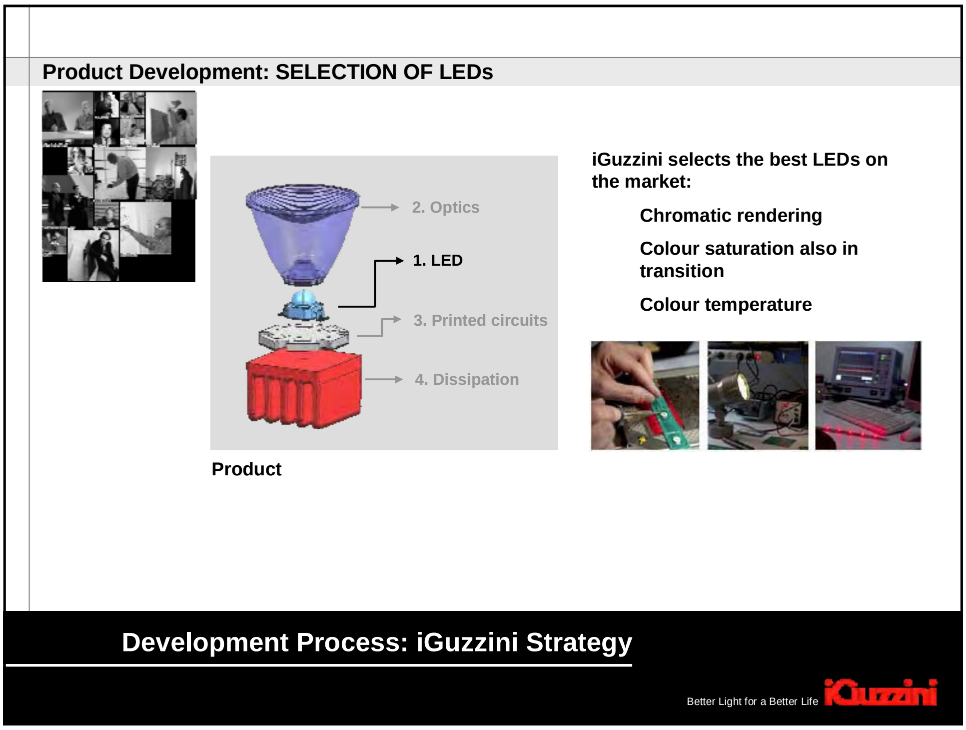
Better Light for a Better Life iGuzzini

- CO_2: for an ethics of Light according to iGuzzini illuminazione

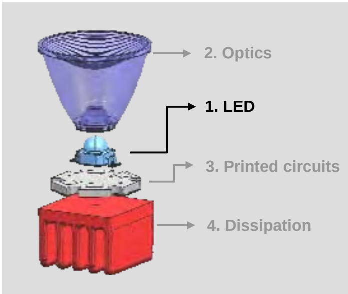
Euroluce 2007

Better Light for a Better Life iGuzzini


Product Development
2. Optics
1. LED
3. Printed circuits
4. Dissipation
Product
Management of Light:
Control Systems
Development Process: iGuzzini Strategy
Better Light for a Better Life
iGuzzini

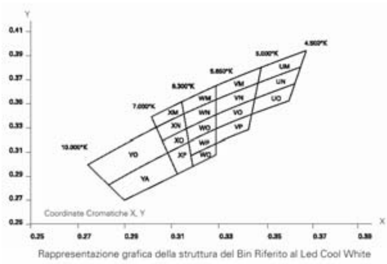

Product Development: SELECTION OF LEDs
2. Optics
1. LED
3. Printed circuits
4. Dissipation
Product
iGuzzini selects the best LEDs on the market:
Chromatic rendering
Colour saturation also in transition
Colour temperature
Development Process: iGuzzini Strategy
Better Light for a Better Life
iGuzzini

Product Development



Product

Colour temperature

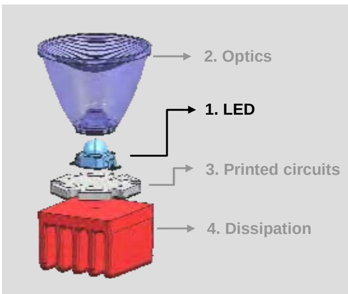


Through a careful binning process, iGuzzini performs a complete check and qualitative selection of LEDs, according to the colour temperature of each LED. A specific colour range is identified in order to guarantee constant colour temperature.

Development Process: iGuzzini Strategy

Better Light for a Better Life iGuzzini

Product Development



Product

LED Technology Development

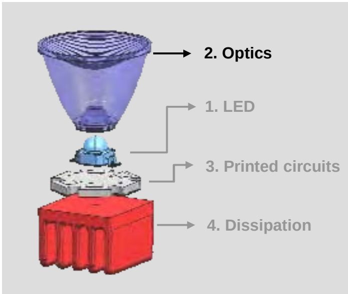
lampada	efficienza luminosa lm / Watt		durata della lampada h	
LED	2007	2012	2007	2012
	75	150	30.000	50.000
Incandescenza	16		750	
HAL	20		4.000	
Fluorescenza	85		8.000 - 20.000	
HIT	90		10.000	

The table shows the future scenario of the LED technology, with expectations and comparisons with other light sources. The luminous efficiency of LEDs will double in 2012 and triple in 2020, with consequent increase of energy saving.

Development Process: iGuzzini Strategy

Better Light for a Better Life iGuzzini

Product Development: OPTICS



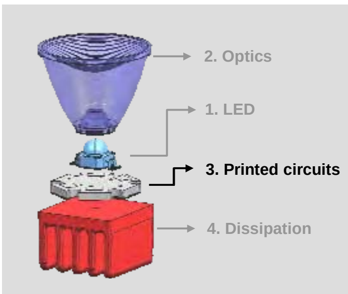
Product

iGuzzini designs thermoplastic optics in its own prototyping department

Development Process: iGuzzini Strategy

Better Light for a Better Life iGuzzini

Product Development: PRINTED CIRCUITS



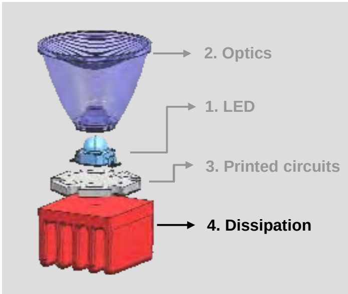
Product

Printed circuits are produced thanks to advanced technology

Development Process: iGuzzini Strategy

Better Light for a Better Life iGuzzini

Product Development: DISSIPATION



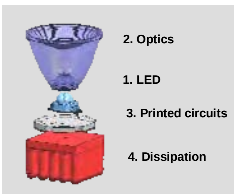
Product

Dissipators are designed according to safety principles and adapted to the needs of industrial designers

Development Process: iGuzzini Strategy

Better Light for a Better Life iGuzzini

In practical terms ….



Woody:

35W Hal Gy6,35 inductive transf

35W Hal Gy6,35 electronic transf

12W Power LED (50lm/W)

Luminous flux 600 lumen

10 h operation per day	
12 Power LED (50 lm/W)	
Absorbed power	13,5 W*h
Absorbed power * year	49 KWh*year
CO_2 amount per year	20 Kg
Expected lamp life	30,000 h
Maintenance cycle	8.2 years

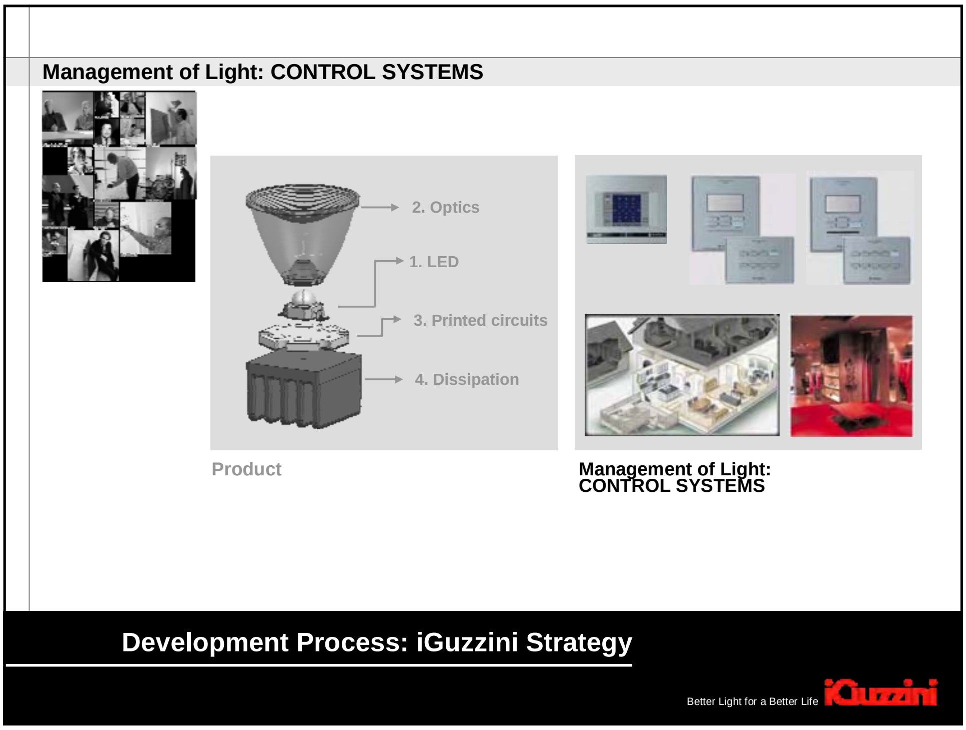
10 h operation per day	
35W electronic transf	35W inductive transf
38 W*h	42 W*h
139 KWh*year	184 KWh*year
58 Kg	77 Kg
4,000 h	2,000 h
1,1 anni	0.6 years

Results		
Δ LED/ELECTRONIC - Δ LED/INDUCTIVE		
Absorbed power	24,5W*h	28,5 W*h
Absorbed power *year	90 KWh*year	135 KWh*year
CO_2 amount	38Kg	57 Kg
Expected lamp life	26,000h	28,000 h
Maintenance cycle	6 very 8 years	12 every 8 years

Development Process: iGuzzini Strategy

Better Light for a Better Life iGuzzini


iGuzzini LED PRODUCTS
Le Perroquet spot led
Parallel quadrato led
Microframe led RGB
Linealuce led RGB
Light Up professional / light led RGB
Woody led RGB
Maxi Woody led RGB
Platea led RGB
Glim Cube led RGB
Tee led
Light Up Balisage led
Development Process: iGuzzini Strategy
ISPRA 3.4.2007
Better Light for a Better Life
iGuzzini


Management of Light: CONTROL SYSTEMS
2. Optics
1. LED
3. Printed circuits
4. Dissipation
Product
Management of Light: CONTROL SYSTEMS
Development Process: iGuzzini Strategy
Better Light for a Better Life
iGuzzini

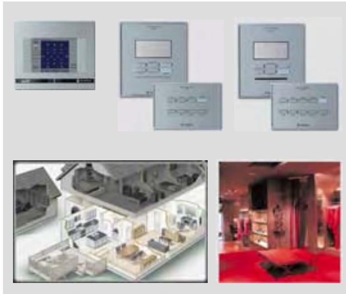
Management of Light: CONTROL SYSTEMS

iGuzzini works with the most reliable companies in the field of electronics:

in order to design drivers to control the technical specifications of chip manufacturers

in order to use the best communication buses according to the specific product (DALI, DMX, LON, ecc...)

in order to develop innovative software applications that ensure user-friendly and intuitive control panels for LED products



Management of Light:
CONTROL SYSTEMS

Development Process: iGuzzini Strategy

Better Light for a Better Life

Management of Light: CONTROL SYSTEMS

MASTER 1

Management of light scenes in individual settings

SCENE EQUALIZER

Management of light scenes in multi-settings

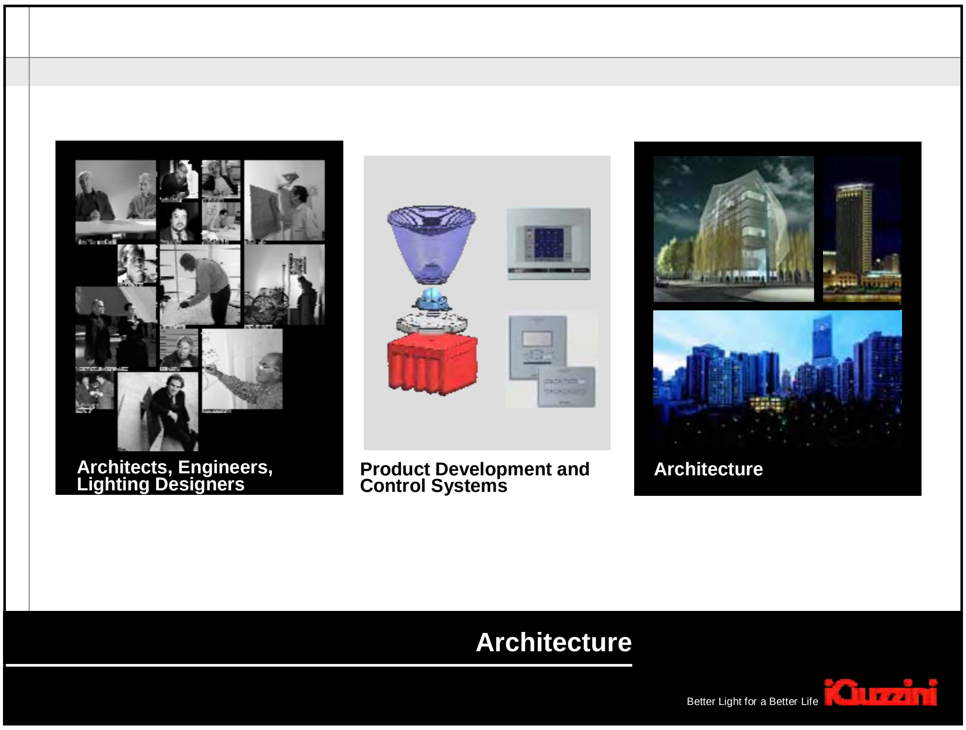
COLOUR EQUALIZER

Control system for colour lighting in one or more settings

Development Process: iGuzzini Strategy

Better Light for a Better Life

GITRONICA
Gestione della Luce: SISTEMI DI CONTROLLO
Scene Equalizer
Colour Equalizer
DLC Master1
Processo di Sviluppo: iGuzzini Strategy
Better Light for a Better Life
iGuzzini



Architects, Engineers, Lighting Designers
Product Development and Control Systems
Architecture
Architecture
Better Light for a Better Life
iGuzzini

LEDs ARCHITECTURE **RESEARCH**

Innovation² = EcoLed

Dinamicity & Visual Wellbeing

"Standard Technology"- Minimum visual impact

RESEARCH & SOLUTION…iGuzzini Partner For Better Architecture

Architecture

Better Light for a Better Life iGuzzini

LEDs ARCHITECTURE **RESEARCH**

Innovation² = EcoLed

LEDs mean innovation. Solar-powered LEDs are innovation at a square power rate!
Architect Geli talks about Alternative LEDs (alternative energy)
In recent years a new form has been experimented by contemporary architecture: the Envelope.
Buildings and structures are wrapped in a structural veil and .... in this case the veil is:
- luminous
- not only: luminous and dynamically intelligent (sensors)
-not only luminous: it's Eco-Lighting because it reacts to absorbed energy

It becomes the luminous shadow of the day …. It reflects yesterday's luminosity ...

Architecture

Better Light for a Better Life iGuzzini

Hotel Habitat, Enric Ruiz Geli (2005-2011)

Location:
Barcelona (Spain)

Architectural project:
Enric Ruiz Geli

Lighting project:
Enric Ruiz Geli

Lighting consultancy:
iGuzzini illuminazione

Products:
"the artificial leaf"


CATALUÑA

Innovation² = EcoLed

Better Light for a Better Life iGuzzini

Hotel Habitat, Enric Ruiz Geli (2005-2011)

Architectural concept:

"... your room is a tree ..."

Each fitting is similar to a artificial leaf ...

Innovation² = EcoLed

Better Light for a Better Life iGuzzini

LEDs ARCHITECTURE RESEARCH

LEDs: Dynamicity & Visual Wellbeing

Shanghai, China: dynamicity is for sure the best word to describe the cultural, social, economic world of today's China.
Architecture is futuristic, and most of all visible.
Buildings become huge communication screens.

iGuzzini is the protagonist of two prestigious projects: a hotel building, and a green architectural work, that is to say a large park in Shanghai.
The common element is dynamicity, expressed through dynamic light.

Architetture

Better Light for a Better Life iGuzzini

Shimao China Hotel

Location:
Shanghai (China)

Lighting Consultancy:
Jax Wang, director of Lighting Design Department, China

Products:
glim cube (led + control system)

Woody, multi-frame woody

The Shi Mao Hotel located on the north bund – the center of Shanghai

From this hotel we can have full view of Shanghai.

Video

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Better Light for a Better Life iGuzzini

Shimao China Hotel

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Shimao China Hotel

Lighting Concept

Main Area :

- Zone 1 - Top Light
- Zone 2 - Vertical Light
- Zone 3 - Balcony Light
- Zone 4 - Podium Light
- Zone 5 - Entrance Light

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Zone 6:

Star Envelope

Lighting Concept: dynamic surface reproducing a "starry sky"

Building façades are converted into decorative elements with huge visibility

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Glimcube installation info.

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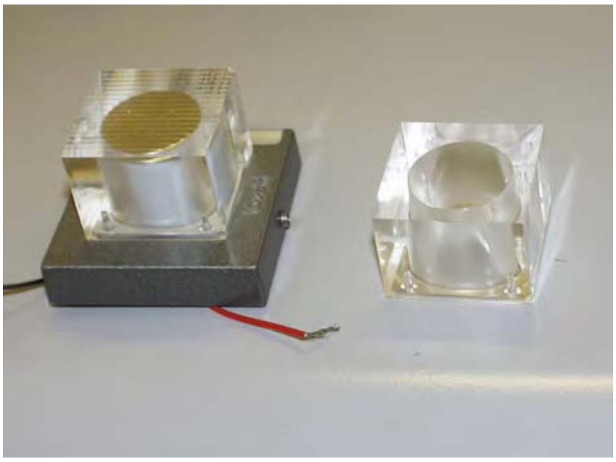

Product

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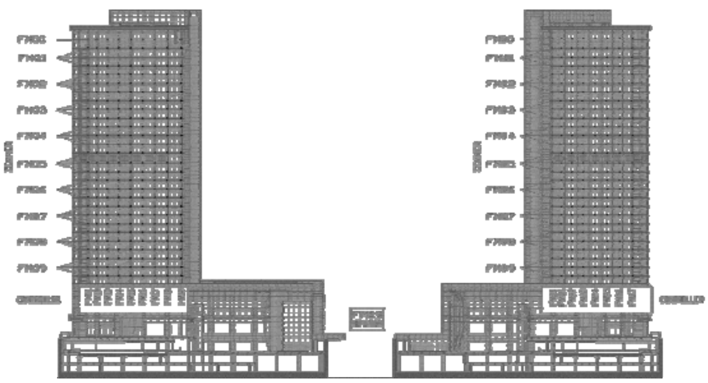

Plant Scheme:

4 led per NODE

3 GLIMCUBE per NODE

3 free-out puts

9 coloumns/ 8 coloumns

50 pre-programmed scenes (rain, ping-pong, Hola, Zig-zag, Words,...)

LONWorks

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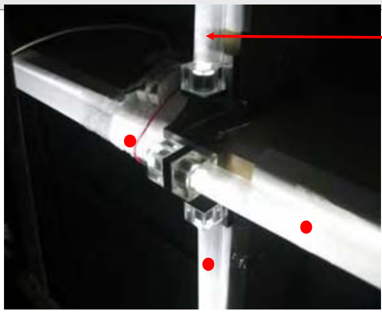

special pc tube to direct the LED flux reproducing the magic star effect for long distances

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Tests

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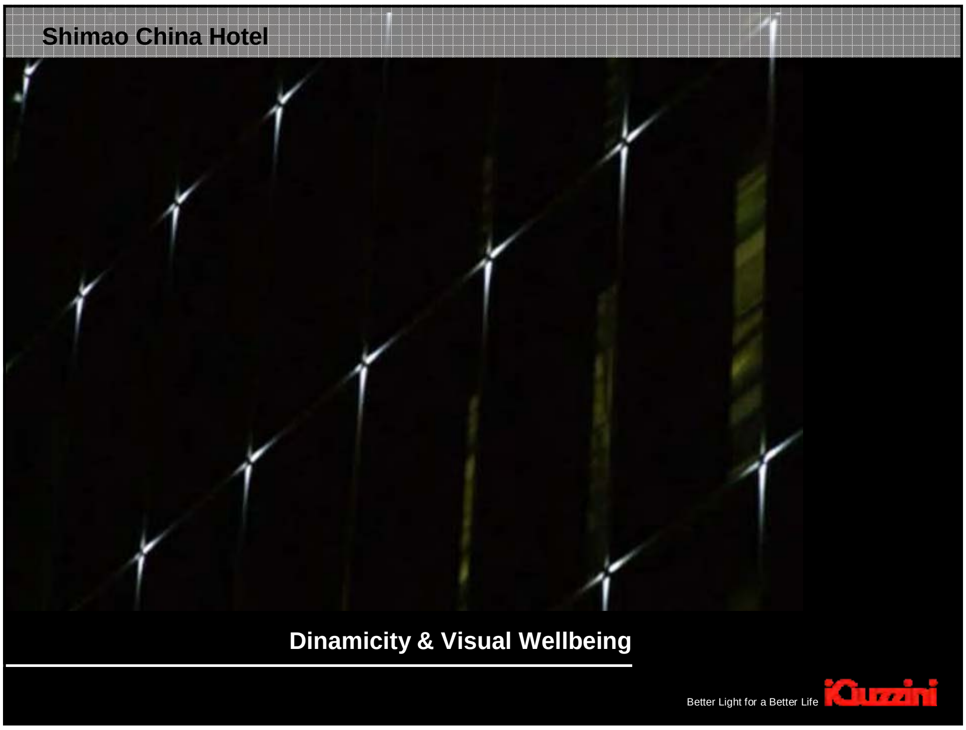
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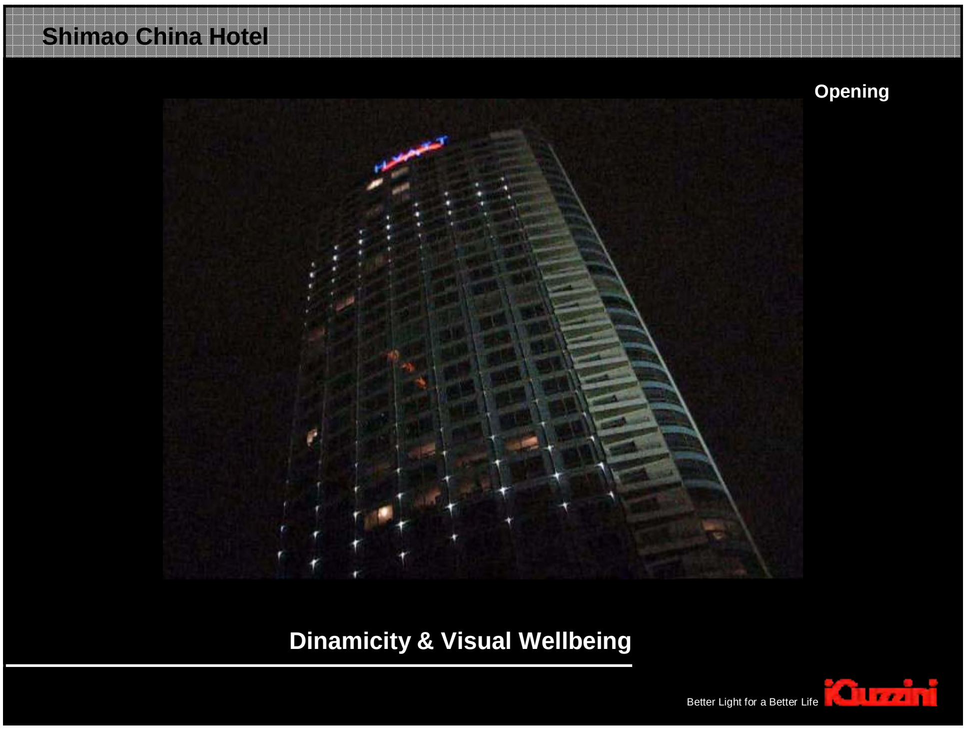
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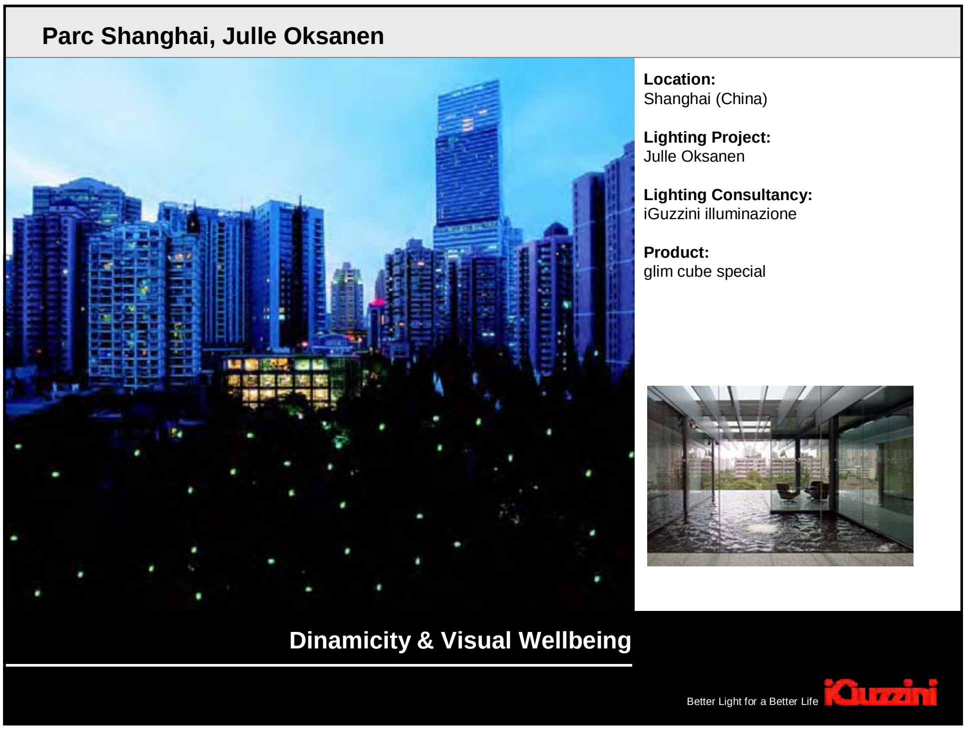
Parc Shanghai, Julle Oksanen
Location:
Shanghai (China)
Lighting Project:
Julle Oksanen
Lighting Consultancy:
iGuzzini illuminazione
Product:
glim cube special
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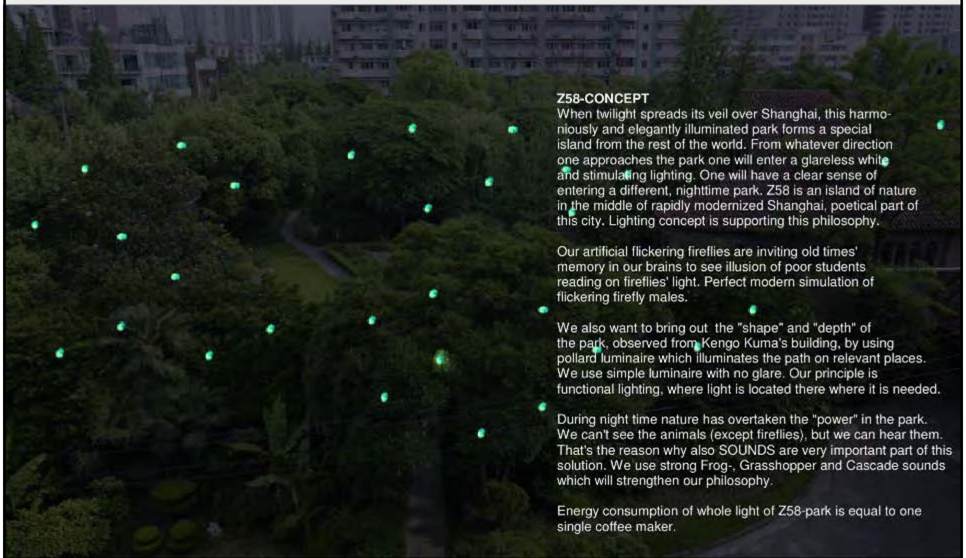
iGuzzini

Parc Shanghai, Julle Oksanen



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Parc Shanghai, Julle Oksanen

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Parc Shanghai, Julle Oksanen

FIREFLIES - LIGHT LOVERS OF THE NIGHT

Night falling over Z58-Park, everything is so calm and quiet, twilight spreads its veil over Shanghai, but the energetic plants are still growing and expanding during the night. You almost can touch the night time nature growing. It differs from the hectic daylight growing time. Power of life has overtaken the place. We are touched by this power - not only growing plants, but also light is life - power - the atmosphere of the fireflies winking lights is so beautiful, warm and inviting greenish...showing the life...male and female stuff...power of life.

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Parc Shanghai, Julle Oksanen

ARTIFICIAL FIREFLY
Firefly simulation is done by using 160 pcs of **Iguzzini**'s dimmable 1W **Glim Cube** luminaires. 80 pcs of Amber color and 80 pcs of Green color. In order to be able to simulate fireflies as in reality, we have to be able to operate them without limits. Dimming and shutting down completely and flickering. This all is possible with Iguzzini's operating system (see page 6).

Glim Cubes have to be modified so, that every side is illuminated. That's why the minimum custom made operation is to get rid of the riffling. We propose sandplasting on each side. We think that it is enough and that "Black tube" inside the Cube can stay. Fast demonstration can be done in Zhongtai's office by using existing Glim Cube, proper tool to get rid of the riffling, sandpaper and green film.

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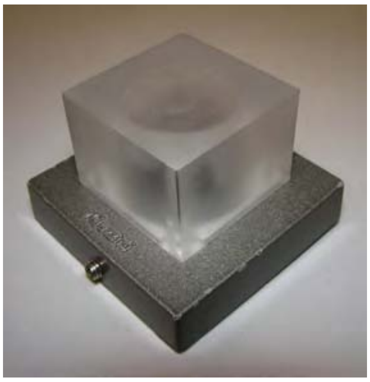
Parc Shanghai, Julle Oksanen

FI87.715 GLIM CUBE B602 W1 LED GREEN 1 W W/Flat S



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Better Light for a Better Life iGuzzini

LEDs ARCHITECTURE

LED:
"Standard Technology"
Minimum visual impact

In recent years iGuzzini has developed LED products in reply to the unexpressed needs of contemporary architecture.
Today those products are used for large prestigious projects.
This shows the importance of state-of-the—art research and investigation to anticipate modern needs.

Let's see three of our projects that use standard products..

Architetture

Better Light for a Better Life iGuzzini

The Red Km, Scientific and Technological Park (2006)

Location:
Bergamo (Italy)

Architectural Project:
Jean Nouvel

Lighting Project:
Jean Nouvel

Lighting Consultancy:
iGuzzini illuminazione

Products:
glim cube

“one of the most original and advanced initiatives in Europe for infrastructures dedicated to research and development activities ...

... presented at Milan Triennale ...””

“Standard Technology” – Minimum visual impact

Better Light for a Better Life iGuzzini

The Red Km, Scientific and Technological Park (2006)

Offices:
Optica

Meeting Room:
Suspended fluorescent Castello

Canteen:
Easy, Tray

Exteriors (park, paths):
iWay (20 W metal halide, with anti-light pollution rim), LED recessed luminaires

Lighting Concept in Exteriors: softened lighting without differentiation between green areas and paths, “paths must fade out into the green” Jean Nouvel

“Standard Technology” – Minimum visual impact

Better Light for a Better Life iGuzzini

The Red Km, Scientific and Technological Park (2006)

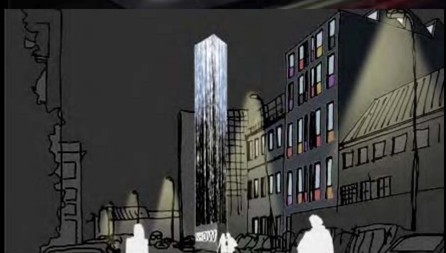
Better Light for a Better Life. iGuzzini

"Standard Technology" – Minimum visual impact

ISPRA 3.4.2007

Better Light for a Better Life iGuzzini

Hotel Nhow, Matteo Thun



Location:
Milan (Italy)

Architectural Project:
Matteo Thun

Lighting Project:
Matteo Thun

Lighting Consultancy:
iGuzzini illuminazione

Products:
glim cube

"Standard Technology" – Minimum visual impact

Better Light for a Better Life iGuzzini

Hotel Nhow, Matteo Thun

LIGHTING PROJECT

EXTERIORS:

Windows of main façade

Three-module Glime Cube

Sill-recessed product

(grazing installation)

Internal courtyard:

Platea on façade, direct lighting

"Standard Technology" – Minimum visual impact

Better Light for a Better Life iGuzzini

Hotel Nhow, Matteo Thun

"Standard Technology" – Minimum visual impact

Better Light for a Better Life iGuzzini

Hotel Nhow, Matteo Thun

"Standard Technology" – Minimum visual impact

Better Light for a Better Life

Varenna

Location:
Varenna (Italy)

Lighting Project:
Piero Castiglioni

Lighting Consultancy:
iGuzzini illuminazione

Products:
glim cube

"Standard Technology" – Minimum visual impact

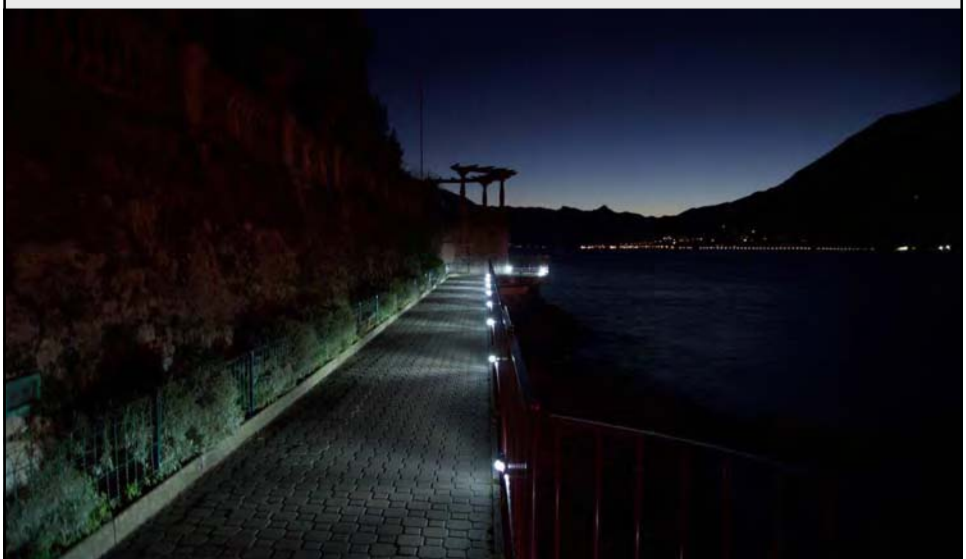
Better Light for a Better Life

Varenna

“Standard Technology” – Minimum visual impact

Better Light for a Better Life

Varenna



“Standard Technology” – Minimum visual impact

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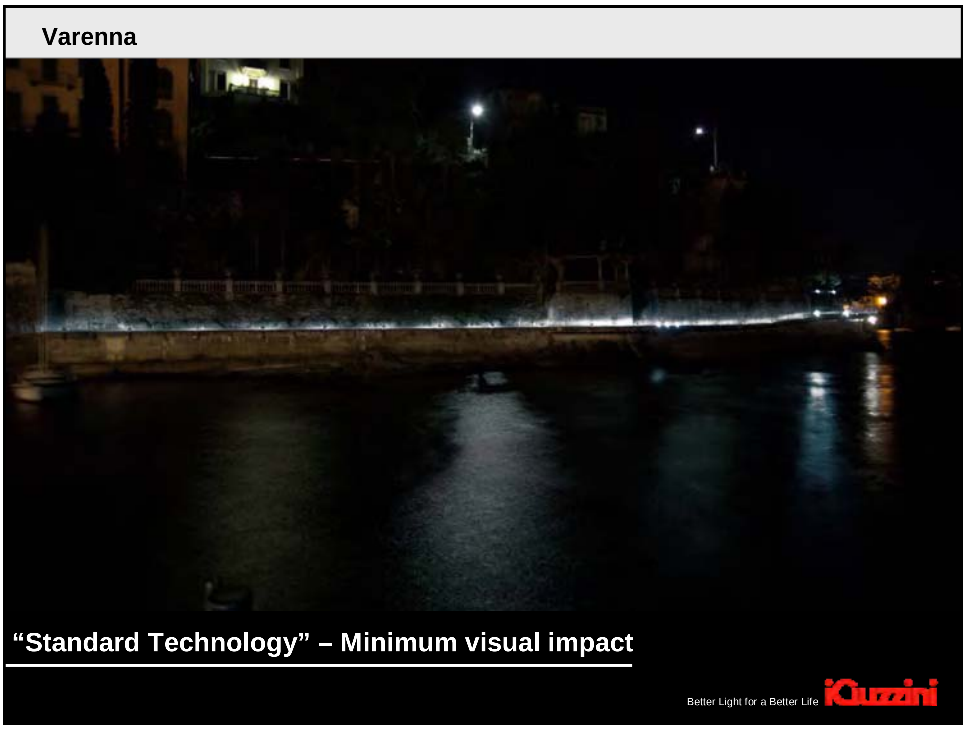
Varenna
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Better Light for a Better Life

European Commission

EUR 23547 EN – Joint Research Centre – Institute for Environment and Sustainability
Title: Proceedings of the International Workshop on: "Status, Prospects and Strategies for LEDs in General Lighting", Ispra, Italy, 3-4 May 2007
Authors: Paolo Bertoldi and Bogdan Atanasiu
Luxembourg: Office for Official Publications of the European Communities
2009 – 376 pp. – 21 x 29,7 cm
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-10328-5

Abstract
This book contains the Proceedings of the International Workshop on "Status, Prospects and Strategies for LEDs in General Lighting", Ispra, Italy, 3-4 May 2007.
The European Commission DG-Joint Research Centre organised a workshop focused on the latest R&D, market information, and application on LED for general lighting, in order to gather the latest information to the topic. Researchers, market analysts, LED manufacturers, luminaire manufactures and lighting experts were invited to contribute their views on the possible use of LEDs for general lighting. The presentations were made by the leading experts and market actors and covered the technical and commercial advances in the LED technology developed for lighting applications, as well as EU policies and programmes supporting energy efficient lighting.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

LB-NA-23547-EN-C

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